A Test Methodology for Assessing Demining Personal Protective Equipment (PPE)

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ABSTRACT

To reduce human casualties associated with demining, a wide range of protective wear has been designed to shield against accidental detonation of antipersonnel (AP) landmines. Injury protection offered by personal protective equipment (PPE) may include, but is not limited to, head/face protection and thorax protection that may offer the potential for substantial defense against fragments, blunt force trauma, burns, and other consequences of mine blasts. In this study, five commercially available PPEs were evaluated. These suits represent a wide range of materials and armor masses. In addition, the PPEs offer varied areas of head, neck, thorax and extremity coverage.

This study utilized the Hybrid III dummy, an instrumented biofidelic surrogate that is anthropometrically similar to the human body. The primary dummy was a 50th percentile male, anthropometrically scaled to the average North American adult male. Tests were conducted with both an unprotected dummy and a dummy clothed with one of the five commercially available PPEs. Based on recorded dummy values, injury risk assessments were made using human or animal injury models. The PPEs were evaluated against two levels of simulated mines containing 100 g and 200 g of C-4 explosive against a widely fielded antipersonnel mine, the PMN containing 240 g of TNT. The test matrix consisted of 102 tests to confirm repeatability and robustness of the dummies, as well as to evaluate the five PPEs, two size dummies, and two positions (kneeling and prone).

The goal of this study was to determine the level of protection offered to the head, neck, and thorax by the protective equipment. Correlations were drawn between injury risk and various parameters such as PPE mass, projected area, and dummy coverage area. The effect of certain PPE design features was significant. For example, higher mass PPE helmets resulted in lower head accelerations and lower neck moments. This was due to the increased inertia of the dummy by the added mass of the protective equipment. However, those PPEs that presented a larger projected frontal area to the blast wave resulted in higher total momentum transfer, and increased peak load, moment, and acceleration. Two of the PPEs that were evaluated did not include a helmet. The lack of helmet reduced the projected area and thus the loading area. However, this significantly increased the risk of injury by reducing the head/neck inertia and increased susceptibility to fragments and blunt trauma.

Introduction

The human toll from antipersonnel mines is large. The United Nations estimates that there are over 100 million antipersonnel mines deployed worldwide [UN-2000]. An estimated 20,000 civilians die each year from landmine explosions, thousands more are wounded and maimed. As there is still no inexpensive and reliable mechanical technique for removing antipersonnel mines, human deminers will be used for the foreseeable future to protect the general population from the menace of landmines. To decrease the human toll from demining, protective equipment should be used. For comprehensive protection, the demining ensemble may include head/face protection, thorax protection, and extremity protection including gloves and boots as shown in

Figure 1. This ensemble offers the potential for substantial protection against fragments, blunt force trauma, burns, and other consequences of mine blasts. However, there is no established standard for testing demining personal protective equipment (PPE). *Without some objective procedure to evaluate the risk of injury while wearing protective gear, the design of such demining equipment is guesswork* and may produce additional risk of unforeseen injury.

The principal objective of this study is to develop and test an objective methodology for humanitarian demining PPEs that can evaluate the risk of human injuries from mine blasts. These injuries include blast injuries to the head and thorax, blunt trauma to the head, neck and thorax, and burns.

Essential elements in the development of this procedure for evaluating the risk of injury while wearing demining PPEs are:

- Robust dummy surrogate with established and applicable injury criteria – positioned in a realistic manner in positions representative of demining (i.e. kneeling and prone).
- Robust instrumentation – data handling consistent with the response.
- Accurate positioning – distance to mine must be consistent and quantifiable.
- Repeatable, quantifiable threat (mine) – with fixed burial and soil characteristics.

Each of these elements is satisfied by the procedure developed in this study and acts to provide an objective criterion for injury and injury performance while ensuring that the resulting criterion is as applicable as possible to the conditions experienced in the real world.

Methodology and Results

Blast testing was performed using Hybrid III dummies as shown in Figure 1. Five styles of PPE suits were tested in 102 blast tests against two simulated mines and one actual mine. These suits were identified as PPE 1 – PPE 5. Baseline tests were performed on unprotected dummies for each position and each of the simulated mines. The same tests were then repeated with the dummies dressed with each PPE. The threats used in this test series were simulated mines that contain 50 g, 100 g, and 200 g of C-4. The Soviet PMN antipersonnel mine was used on 10 shots for comparison explosive yield using two of the PPE styles. The test dummies were placed in two common demining positions, kneeling (k) and prone (p) as shown in Figure 2. To enhance the statistical significance of the test data, three shots were performed for each combination of position, threat and PPE. The 50 g simulated mine was found to not cause injurious loads against the unprotected dummies and was therefore dropped from any of the protected testing.

Figure 1: Simulated Antipersonnel Mine Blast with Hybrid III Surrogate

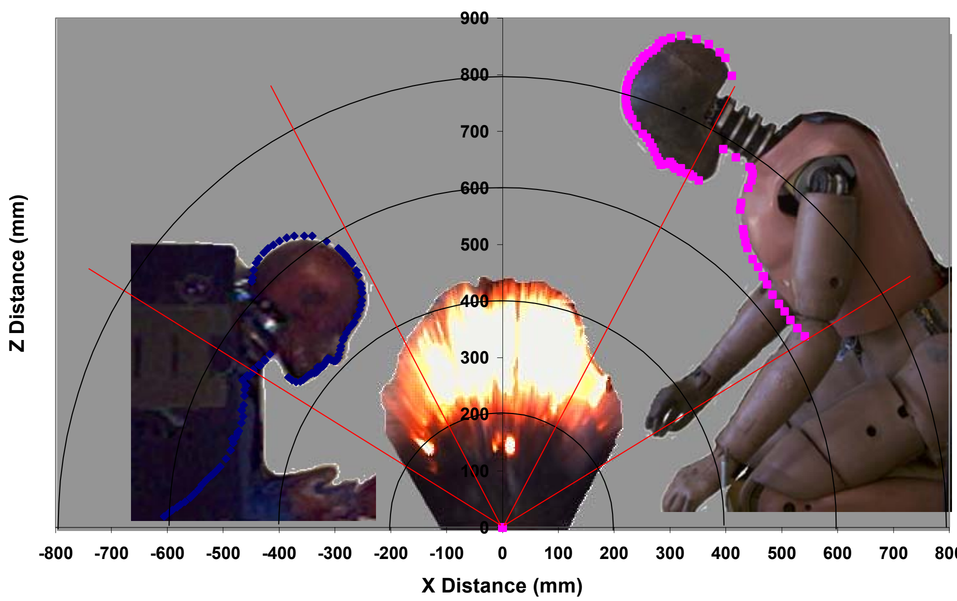

Figure 2: Nominal Kneeling and Prone Positions Relative to the Center of the Mine - Radial Lines at 30^0 and 60^0

Two blast resistant positioning fixtures were used to support and position the dummies and were placed at least 4 meters from the wall and each other to prevent blast interference. These positioning fixtures were developed by a U.S.-Canadian collaboration including U.S. Army CECOM, Canadian Center for Mine Action Technologies (CCMAT), U.S. Army Aberdeen Test Center (ATC), and the University of Virginia. They allow accurate positioning for each shot to within ± 3 mm of reference locations in each spatial axis.

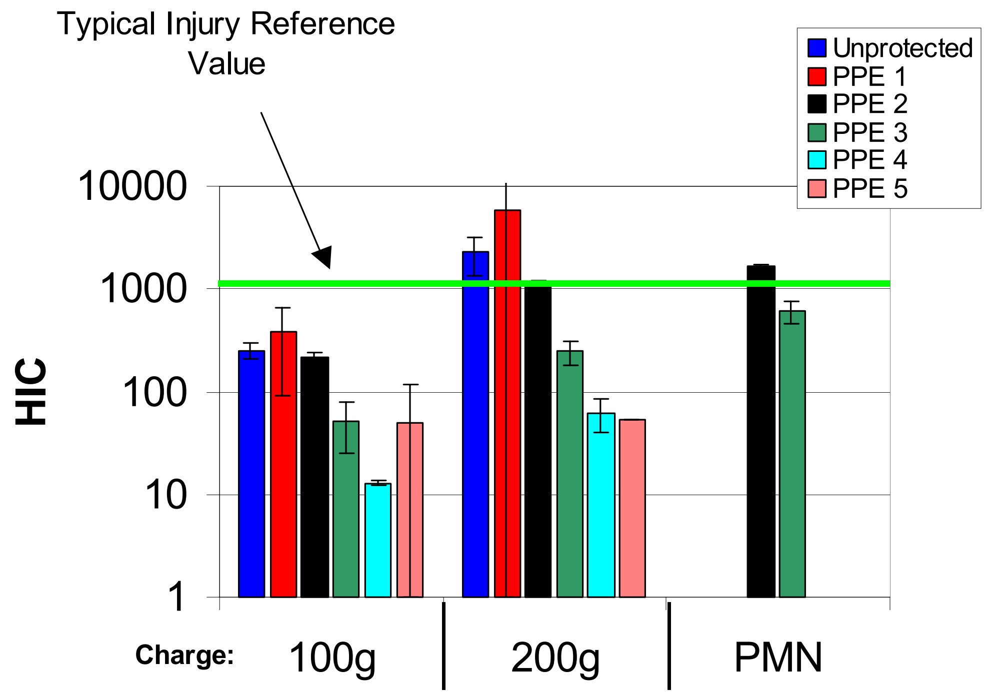

Figure 3: HIC Values for Mine Blast into Kneeling Dummy, All Charge Sizes, All PPEs

For the Head Impact Criterion (HIC), a widely used injury measure for the Hybrid III dummies, the facial protection with PPE 1 did not reduce the risk of head blunt trauma when compared to the unprotected case as shown in Figure 3. This unexpected result may be explained by the physical features of the head protection gear, including the projected frontal area and the helmet mass. First, the heavier helmet/visor sets produced lower HIC values. The two heaviest helmets, those from PPE 4 and PPE 5, performed better than those from the other PPE for dummies in the kneeling position because the larger mass decreases the acceleration of the head, resulting in a smaller HIC value. The mass of the standard Hybrid III head/neck complex is 5.8 kg. So, the 2.6 kg mass of the helmet/visor set from PPE 5 adds approximately 45% more weight to the structure, and probably explains the significant drop in HIC when the helmet/visor from PPE 5 is added to an unprotected dummy.

The peak external pressures for the protected and unprotected dummies at the 100 g and 200 g charge level from the upper left thorax gauges are shown in Figure 4. Approximate durations of these pressure time histories are 0.7 ms. These are compared with the threshold lung damage free field values taken from classic work by Bowen *et. al.* [Bowen-1968]. Both the unprotected and protected dummies show much larger peak pressures for the 200 g charge size than the 100 g charge size. In addition, all of the dummies with PPEs show decreased peak pressures relative to the unprotected dummies except PPE 2 for the 200 g charge size. Complex wave interactions behind the PPEs may be the explanation for the large spread in thorax peak pressures for certain PPEs. However, for both the 100 g and 200 g charge sizes, the peak thorax pressure does not exceed the threshold for blast lung injuries. The complexities of evaluating injury criteria for

near field blasts with complex pressure waves suggest the strong need for an experimental effort to evaluate such waves in an injury model.

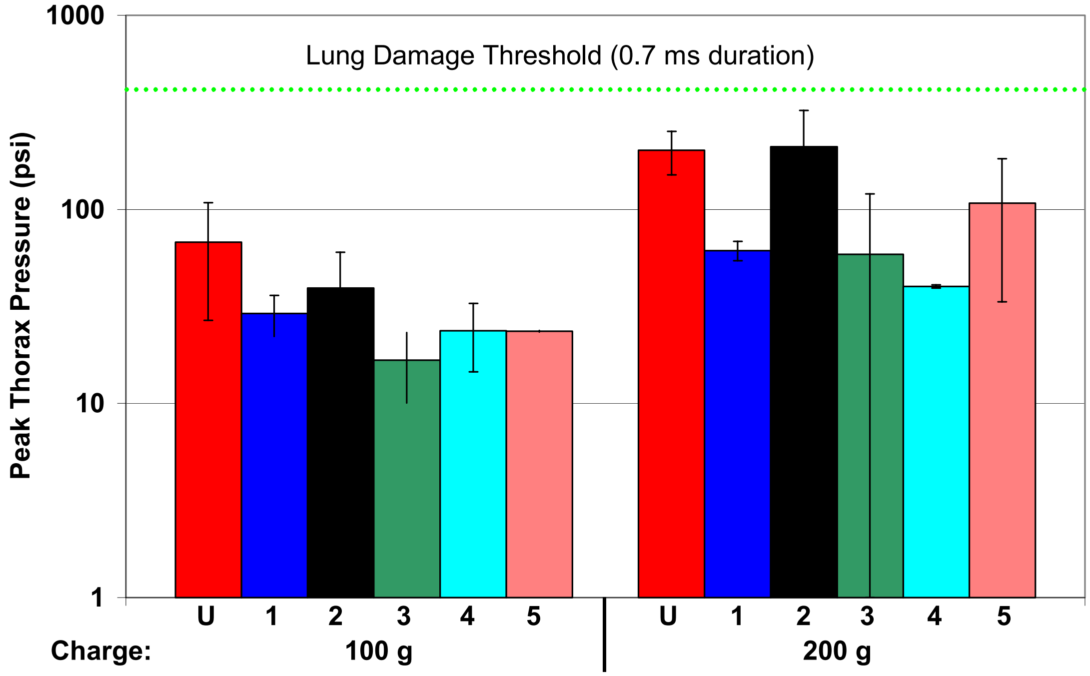

Figure 4: Peak Thorax Pressure for Kneeling Hybrid III 50th % Male Dummies

Conclusions

To summarize, essential elements in the development of a procedure for evaluating the risk of injury while wearing demining protective equipment are:

- Repeatable, quantifiable threat (mine) – with fixed burial and soil characteristics.
- Robust dummy surrogate with established and applicable injury criteria – positioned in a realistic manner in positions representative of demining (i.e. kneeling and prone).
- Accurate positioning – distance to mine must be consistent and quantifiable.
- Robust instrumentation – data handling consistent with the response.
- Reasonable threat level that appropriately identifies the level of protection.

Each of these elements acts to provide an objective criterion for injury and injury performance while ensuring that the resulting criterion is as applicable as possible to the conditions experienced in the real world.

Each of these elements was satisfied in this proposed test methodology. The simulated mines show repeatable pressure time histories, and the largest simulated mine is comparable to an actual mine of the same threat level. Mine burial can be controlled very precisely, and soil characteristics have been fixed.

The Hybrid III dummy has been found to be a robust and repeatable surrogate. None of the dummies used suffered a significant mechanical failure during the testing. The dummies are available in sizes that are anthropometrically similar to a human mid-sized male and similar to a small female. Positioning was accomplished to within ±3 mm relative to the center of the mine with an inexpensive measurement device. Both the kneeling and the prone positions were specified to produce a significant risk of blunt head trauma to an unprotected dummy.

At first glance, it appears that the prone position has a higher risk of neck injury than does the kneeling position. However, it is important to realize the significant difference in nose-to-mine distance for the two positions. For the kneeling position, the dummy's nose-to-mine distance is 65 cm, whereas for the prone position, the distance is reduced to 45 cm. The two positions were **not** selected so that the injury risks for the head, neck, and thorax were nearly equivalent, **but** to directly compare risk of injury between the kneeling and prone positions.

Most of the instrumentation proved robust. For the head and chest accelerometers, the only failures arose from inadvertent wire separation. The head accelerations experienced by the dummies showed a substantial risk of serious head injury from blunt trauma for the larger mines. However, questions remain about the applicability of typical acceleration based injury criteria to mine blasts. *It is recommended that a limited test series be performed with an injury model under blast loading to determine the boundaries of applicability of the currently used injury criteria.*

The neck sensors performed well. The neck showed forcing similar to that seen in automobile impacts for which the sensors were developed. The sensor data showed good differentiation between the level of mine, and was repeatable within a test dummy. The loosening of the neck of Dummy B compromised the comparison of Dummy A to Dummy B for neck loading. This indicates the large vibration loads in blast shock loading, not seen in the usual automotive application. For future tests, it is strongly recommended that the dummy neck tensioning be checked regularly during the test series.

The thoracic instrumentation proved generally robust. However, neither the chest displacement nor the Viscous Criterion showed injurious values, even for an unprotected dummy. The sternal accelerometers performed poorly, likely owing to high frequency oscillations in the sternum under blast loading. In future testing, the accelerometer should be mounted on the top of the sternum to avoid some of these oscillations. The upper thoracic pressure sensors proved robust, while the lower pressure sensors failed repeatedly. This may be the result of the greater compliance of the Hybrid III dummy in the lower thorax. All PPEs but one reduced the peak thoracic pressure for both the 100 g and 200 g charge size.

The ear pressure sensors proved relatively robust. Surprisingly, two PPEs with the largest helmets showed increased ear peak pressures relative to the unprotected dummy. This may be attributed to the helmets capturing the pressure wave.

Burn sensors used on the dummy hand and chin in this testing showed a very small risk of serious burns for the mines and depth of burial used. As the sensors are exceedingly delicate for blast testing, it is recommended that no burn sensors be used in subsequent testing.

Finally, this testing showed the strong effect of the blast cone induced by the geometry of the mines and simulated mines. This conical blast pattern limited the risk of injury to the thorax in both the kneeling and the prone positions. To provide the most comprehensive understanding of this effect, a small test series should be performed to quantify dummy response as a function of position in the blast cone.

Design of personal protective equipment against fragment and blast damage when demining involves numerous tradeoffs between protection of various types and ease of use. Such tradeoffs underscore the value of a complete assessment of PPE function that includes ergonomics, protection against fragments and protection against blunt trauma.

Future Work

Several detailed recommendations for future work were developed from this study:

1. This study focused on several 'typical' demining positions. However, there is a strong potential for large changes in dummy response with small changes in position. A limited test series should be performed to investigate the force/response of the dummy from changes in local position and orientation. Such a study will define the necessary precision for dummy positioning which may be crucial in verification of the performance of demining PPEs.

2. The force time histories seen in this study may be outside the range of validity of usual automotive models for which the dummy was developed. It is strongly recommended that a limited test series be performed with a human injury model in several typical test conditions that will verify the use of the dummy surrogates under mine blast conditions.

3. Ear pressures were obtained in this study using a planar pressure sensor mounted to the surface of the Hybrid III dummy head. The human ear acts to amplify incoming pressure waves. So, in concert with an additional dummy test series, it may be prudent to investigate the potential for significant ear damage using a realistic ear form with a pressure sensor located at a distance representative of an eardrum.

4. Finally, the impact of complex blast waves behind body armor is a relatively unexplored area. It is recommended that a limited test series of blast shocks behind body armor be performed with enhanced instrumentation and a human injury model.

1. Introduction and Background

1.1 Introduction

The human toll from antipersonnel mines is large. Though estimates vary on the number of mines deployed worldwide [UN-2000], an estimated 20,000 civilians die each year from landmine explosions. Thousands more are wounded or maimed. As there is still no inexpensive and reliable mechanical technique for detecting and removing antipersonnel mines, human deminers will be used for the foreseeable future to protect the general population from the menace of landmines.

To decrease the human toll from demining, protective equipment should be used. For comprehensive protection, the personal protective equipment (PPE) demining equipment may include head/face protection, thorax protection, and extremity protection including gloves and boots as shown in Figure 5. This suit offers the potential for substantial protection against fragments, blunt force trauma, burns, and other consequences of mine blasts. However, *without some objective procedure to evaluate the risk of injury while wearing protective gear, the design of such demining equipment is guesswork.* Indeed, without an effective injury evaluation technique, design changes in protective equipment may exacerbate certain types of injury. For example, the introduction of body armor in Northern Ireland for protection against blast fragments may have increased the potential for blast lung injuries [Mellor-1989].

Figure 5: Demining PPE (Photo Courtesy Med-Eng, Inc.)

1.2 Objective Test Methodology

The goal in the current study is to develop a procedure to evaluate injuries from mine blasts, borrowing tools from existing techniques when appropriate. This will result in an objective test criterion for the evaluation of the injury risk of a human wearing a PPE. It will allow this injury

risk evaluation for protected or unprotected subjects and will indicate the relative levels of protection for subjects wearing different protective equipment.

For decades, work has been performed on human injury from blunt trauma in the automobile field. Simulated automobile crashes are performed, and the response of the dummy surrogate is taken to represent the response of a human in that crash scenario. This dummy response may be used in an injury model to assess the risk of injury for that crash scenario. Elements of this technique include:

- Biofidelic surrogate – a dummy that is robust, gives a repeatable physical response, and produces a response that is appropriately human-like. A dummy may be physically very simple and may only represent a part of a human. For example, an instrumented beam has been used successfully to represent an arm [Bass-1997]. However, dummies may be very complex, such as the anthropomorphically-correct dummies being developed for the automobile industry. Generally, a surrogate should be as simple as possible while still representing the relevant human response.
- Engineering measurement – a physical parameter such as force or acceleration that may be used to quantify the physical response of the dummy. Dummies may be instrumented to produce accepted or proposed injury criteria.
- Injury risk evaluation – a correlation between an engineering measurement and some injury model. For example, in frontal thoracic blunt impacts, an injury threshold of 60 times the force of gravity is used in the automobile industry.
- Validation by injury model – a correlation between the injury risk evaluation and a physical model of injury. An injury risk model is without value without successful validation using 1) epidemiology or physical reconstruction of an actual injury event, 2) an animal injury model, or 3) a cadaveric human injury model as shown in Figure 6. Development of a relationship between a robust surrogate for injury and a validated injury model is crucial in the success of this approach.

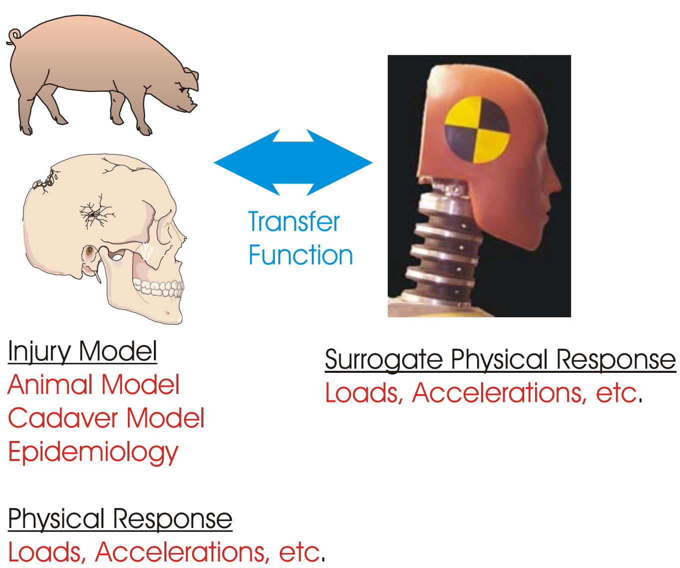

Figure 6: Development of Surrogate Injury Model

Two other important elements of injury simulation may be adapted from those used in automobile testing; use of injury epidemiology to direct testing and injury modeling and use of realistic test conditions. Both limit the risk that an injury simulation is an academic exercise, not applicable to real world conditions.

Widespread use of this technique has saved thousands of lives per year in the automobile industry. Indeed, all automobiles and safety restraints, including air bags, are evaluated using dummy surrogates. As there are similarities in human blunt trauma in an automobile crash and in a blast event, aspects of this technique may be adapted for use in determining injury from mine blasts. The current study builds on several previous test series using Hybrid III dummies and simulated mines to evaluate the performance of demining PPEs. These test series include work performed under the auspices of the Canadian Center for Mine Action Technologies (CCMAT) [c.f. Bergeron-2000] and the U.S. Army – Communications-Electronics Command (CECOM) Countermine [c.f. Chichester-2000].

The tools used in the automobile industry, however, may not be directly applicable to mine blasts for two reasons. First, automobile crashes and mine blasts are substantially different physical phenomena. While both automobile crashes and mine blasts may involve blunt head and chest trauma, mine blasts may have substantial shock wave effects, burns, and other blast phenomena. Second, the events may occur on significantly different timescales. Automobile crashes have injury timescales of approximately 5-100 milliseconds, but injuries in mine blasts may occur 10 to 100 times faster. These timescales have an effect on dummy surrogate response, and the timescale of mine blast injuries may be outside the validity of the injury models used in the automobile industry. So, tools used in the automobile industry must be adapted for use in mine blast testing to effectively assess the risk of injury while demining wearing protective PPEs.

1.3 Epidemiology

Another important element in the effective design and evaluation of protection from injury is the epidemiology of the occurrence of those injuries in the field. Initial efforts to categorize injuries from humanitarian deminers [Landmine-2000] have identified the most significant injuries from mine blasts. Epidemiology, however, is a moving target, and future efforts to categorize ongoing injuries and their causes are crucial. For instance, the use of protective features may change the types of injuries experienced and could warrant changes in the focus of injury protection. A clear example of this came with the widespread use of automobile driver-side air bag restraints. Use of such systems resulted in a substantial decrease in fatal head and thorax trauma, but also led to an increase in the occurrence of debilitating leg injuries.

The types of injuries encountered in a number of demining incidents have been summarized in a groundbreaking report [Landmine-2000] as shown in Figure 7. Fatal injuries include blunt trauma to the head and chest, including blast lung, shock, and multi-system trauma. Blast injuries may also include blast-induced trauma to hearing, burns, and trauma from whole body translations with injury patterns similar to falls. To provide a realistic assessment of injury from mine blasts, injuries from these body regions, especially blunt trauma that may arise while protected, must be included in the injury risk assessment.

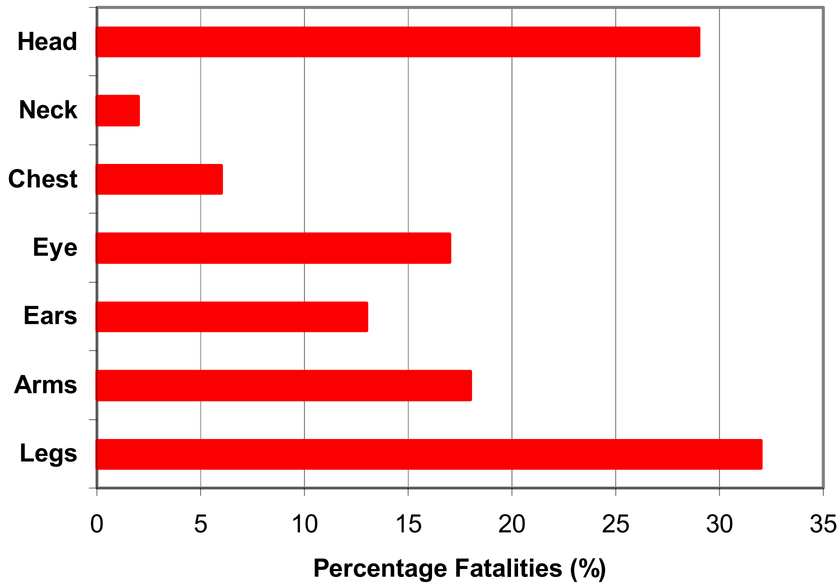

Figure 7: Injuries from AP Landmines Sustained in Demining Incidents [Landmine-2000]

1.4 Dummy and Instrumentation

Simulation of a realistic test condition is especially important in mine blast testing. A high-speed photograph of a simulated mine blast with a dummy surrogate is shown in Figure 9. The force on a human chest or head is related to the pressure from the blast wave and streaming flow from the blast ejecta. Since pressure falls rapidly from the blast and the streaming flow is highly directional, the dummy surrogate position in the blast is vitally important in a realistic simulation. A field survey found that 91% of demining blast incidents occur with the victim within 1 meter of the mine [Landmine-2000]. It is clear, however, that close enough to a large mine blast there may be substantial injury using any personal protective equipment. So, a balance must be maintained between the desire for test realism and the desire to evaluate the worst case in mine blast injuries.

The Hybrid III dummy, widely used in the automobile industry for blunt impact, was selected for this test series. The reason for this selection was twofold. First, the dummy has validated frontal blunt impact injury criteria that may be useful for characterizing demining injuries. Second, it is relatively inexpensive, robust, and widely available. Full dummy surrogate development can be expensive.

A number of different Hybrid III dummies exist that are scaled for different size test subjects. As changes in anthropometry may change risk of injury, for accurate response, the dummy selected should be most representative of the population modeled. Indeed, the effect of anthropometry may be large. Worldwide anthropometry of the average male is shown in Figure 8 [Jurgens-1990]. To see the effect of body anthropometry, if the distance of the body to the mine when demining is taken to be roughly proportional to the mean reach (arm length), the average Southeast Asian male is approximately 70 mm closer to the blast than the average North

American male. This may substantially increase the risk of head or thorax injury in demining for the average Southeast Asian male. Further, there are large numbers of mines in West Africa and Southeast Asia, where populations have relatively short arms and/or stature. So, it seems essential that the small Hybrid III dummy be incorporated into mine protective equipment testing.

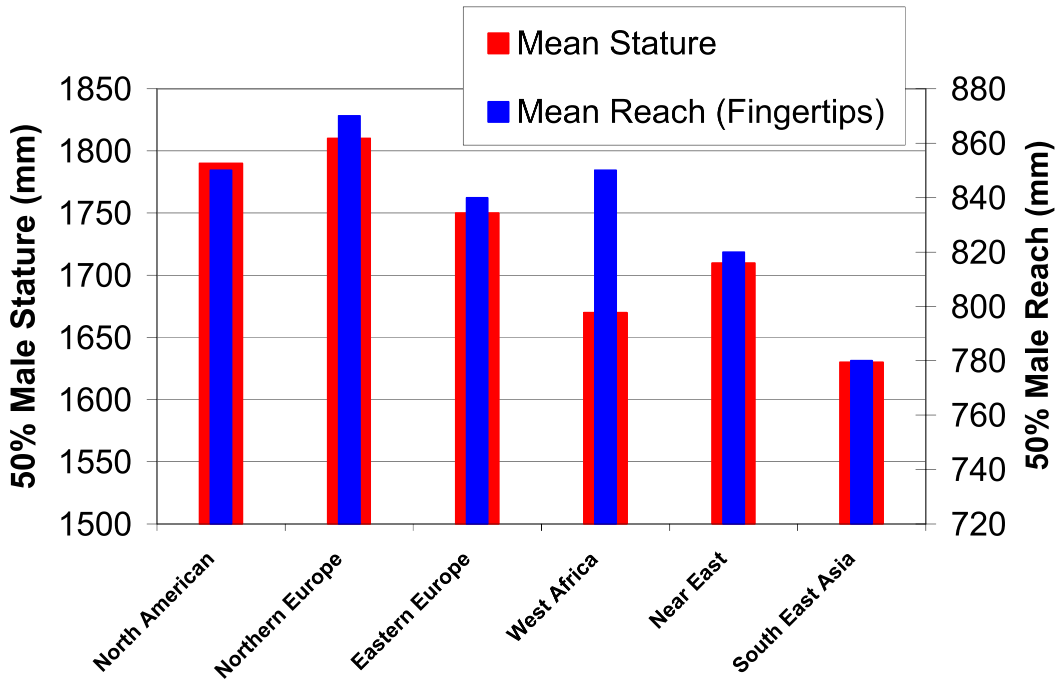

Figure 8: Selected Worldwide 50th Percentile Male Stature and Reach

Two pedestrian version 50th percentile male Hybrid III anthropomorphic dummies, denoted (A) and (B), were used in this test series. One is shown in Figure 9. These dummies, used in automobile crash testing, are particularly useful in estimating the risk of frontal blunt trauma and are validated for frontal blunt impacts to both the head and the chest. In addition, a Hybrid III 5th percentile female dummy was used in selected shots to represent deminers with smaller statures [Bass-2000]. The dummies were placed in each of two positions, kneeling and prone, as discussed in the following section. Tests were performed using unprotected dummies and dummies in each of five humanitarian demining PPEs.

Figure 9: Simulated Antipersonnel Mine Blast with Hybrid III Surrogate

The Hybrid III dummies were instrumented with acceleration-sensing transducers, force-sensing transducers, displacement transducers, and pressure transducers to evaluate head, neck, and thoracic trauma as shown in Table 1. The data from these transducers may be used with accepted injury thresholds and risk functions to determine the risk of injury in a given test condition as reported below. Instrumentation data was sampled at 200 kHz with a 40 kHz antialiasing hardware filter.

Transducer	Location	Evaluation	Sensor
Accelerometer (Triax)	Head Center of Gravity	Head Blunt Trauma	Endevco 7270A-6k
	Chest Center of Gravity	Thorax Blunt Trauma	Endevco 7270A-6k
Load Cell	Upper neck	Neck Blunt Trauma	Denton Upper Neck Load Cell
Accelerometer	Sternum	Thorax Blunt Trauma	Endevco 7270A-6k
Displacement Transducer	Sternum	Thorax Blunt Trauma	Servo 14CB1-2897
Pressure Transducer	Thorax: skin surface, between 3^{rd} and 4^{th} rib	Thorax Blast Lung	Kulite XCQ-093-500A Kulite LQ-125-500A
	Head, skin surface, mounted laterally at ear location	Ear Blast Damage	Kulite XCQ-093-500A
Thermocouple in Skin Simulant	1 each, thorax, head, hand	Thermal Blast Damage	Omega 0.5 mil and Omega 3 mil bare wire gages
Pressure Gauge	Free field at the same x y locations as ear and thorax	Free Field Pressure	PCB 102-A04

Table 1: Instrumentation and Trauma Evaluation

To summarize, essential elements in the development of a procedure for evaluating the risk of injury while wearing demining protective equipment are:

- Robust dummy surrogate with established and applicable injury criteria – positioned in a realistic manner in positions representative of demining (i.e. kneeling and prone).
- Robust instrumentation – data handling consistent with the response.
- Accurate positioning – distance to mine must be consistent and quantifiable.
- Repeatable, quantifiable threat (mine) – with fixed burial and soil characteristics.

Each of these elements acts to provide an objective criterion for injury and injury performance while ensuring that the resulting criterion is as applicable as possible to the conditions experienced in the real world.

In subsequent sections, the test methodology, dummy, positioning instrumentation, and test results are discussed. These are followed by conclusions on the suitability of this test methodology to repeatably characterize demining trauma with and without PPEs.

2. Test Setup, Test Equipment and Personal Protective Equipment

The tests were designed to investigate the suitability of the test methodology chosen to evaluate the risk of injury, especially blunt trauma injury to a deminer wearing a PPE. The PPEs were chosen to represent a range of styles of commercially available PPEs, and the mines were chosen to represent a range of common antipersonnel mine threats. In subsequent sections, the test setup, test equipment, mines, and PPEs are detailed.

2.1 Test Matrix

The test matrix for this study included three primary test variables. These included charge weight, level of PPE protection, and position relative to the center of the mine blast (kneeling vs. prone) as shown in Table 2 using two nominally identical Hybrid III 50th % male dummies. In addition, several tests were performed with a 5th % female dummy to investigate the effect of smaller body mass and stature. These tests will be reported separately.

Five styles of PPE suits were tested in 102 blast tests against two simulated mines and one actual mine. These suits were identified as PPE 1 – PPE 5 as discussed below. Baseline tests were performed on unprotected dummies for each position and for each of the simulated mines. The same tests were then repeated with the dummies dressed with each PPE. The threats used in this test series were simulated mines that contain 50 g, 100 g, and 200 g of C-4. The Soviet PMN antipersonnel mine was used on 10 shots for comparison explosive yield using two of the PPE styles. Further details on the PPE styles and mines are reported below. The test dummies were placed in two common demining positions, kneeling (k) and prone (p). To enhance the statistical significance of the test data, three shots were performed for each combination of position, threat, and PPE. Full test conditions for each test in this series are reported in Appendix A.

Mine\PPE	Unprotected Dummy	PPE 1	PPE 2	PPE 3	PPE 4	PPE 5
50 g	3 K, 4 P	NA	NA	NA	NA	NA
100 g	3 K, 3P	3 K, 3 P	3 K, 3 P	3 K, 3 P	3 K, 3 P	3 K, 3 P
200 g	3 K, 3P	3 K, 3 P	3 K, 3 P	3 K, 3 P	3 K, 3 P	3 K, 3 P
PMN	NA	NA	2 K, 2 P	3 K, 3 P	NA	NA

Table 2: Test Matrix for the Hybrid III 50th % Male Dummy (Number of Shots, P=Prone, K=Kneeling)

2.2 Suits

The five PPE suits chosen for this test series represent the range of demining protective equipment that is commercially available. PPE 1 has a one-piece apron type upper body armor and a visor with a head strap to maintain stability as shown in Figure 10. PPE 2 (Figure 11) consists of vest type upper body armor with small shoulder wings, groin protection extension, and a visor with head strap that is similar to PPE 1. PPE 3 (Figure 12) has a more elaborate jacket, containing shoulder wings, groin protection extension, and removable ballistic inserts for washing ease, and chaps style trousers for frontal leg protection. The ballistic inserts are located

in the upper and lower legs, chest, groin, and main body of the suit. PPE 3 also has a lightweight helmet with chinstrap and visor. PPE 4 (Figure 13) has a vest with brachial artery arm guards (shoulder wings), lower area groin guard, and a heavy helmet with chinstrap and visor. PPE 5 (Figure 14) has an elaborate vest, with shoulder wings and groin protector, and shorts for frontal upper leg protection. PPE 5 also has a heavy helmet with chinstrap and a shorter (smaller frontal area) visor. Protective equipment was placed on the dummies as per manufacturers' instructions to ensure consistent placement and provide consistent coverage. To assess the potential for upper extremity damage from the mine blasts, surgical gloves were used and penetrations of the latex were noted.

Table 3 lists PPE component weights of the suits and visor projected areas. For blunt trauma protection against mine blasts there is a significant tradeoff between ergonomics and protection. For instance, a larger mass helmet may provide greater protection against blunt force trauma, but may be more difficult to wear. Such tradeoffs underscore the value of a complete assessment of PPE function that includes ergonomics, protection against fragments, and protection against blunt trauma.

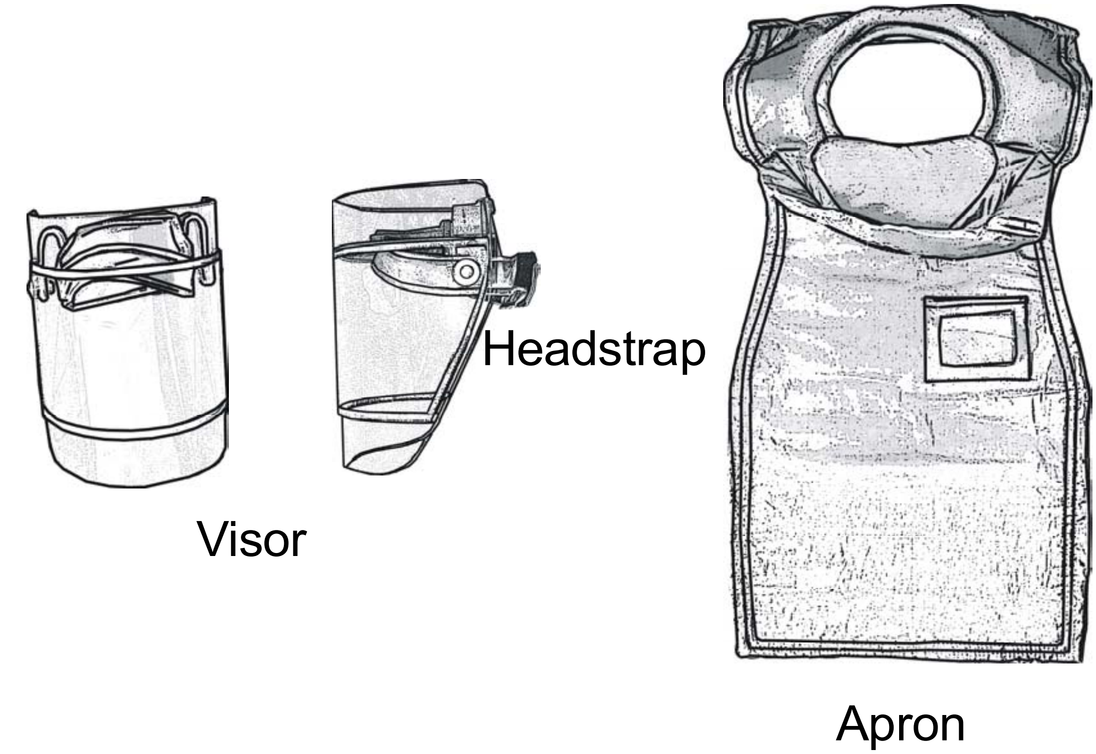

Figure 10: PPE 1

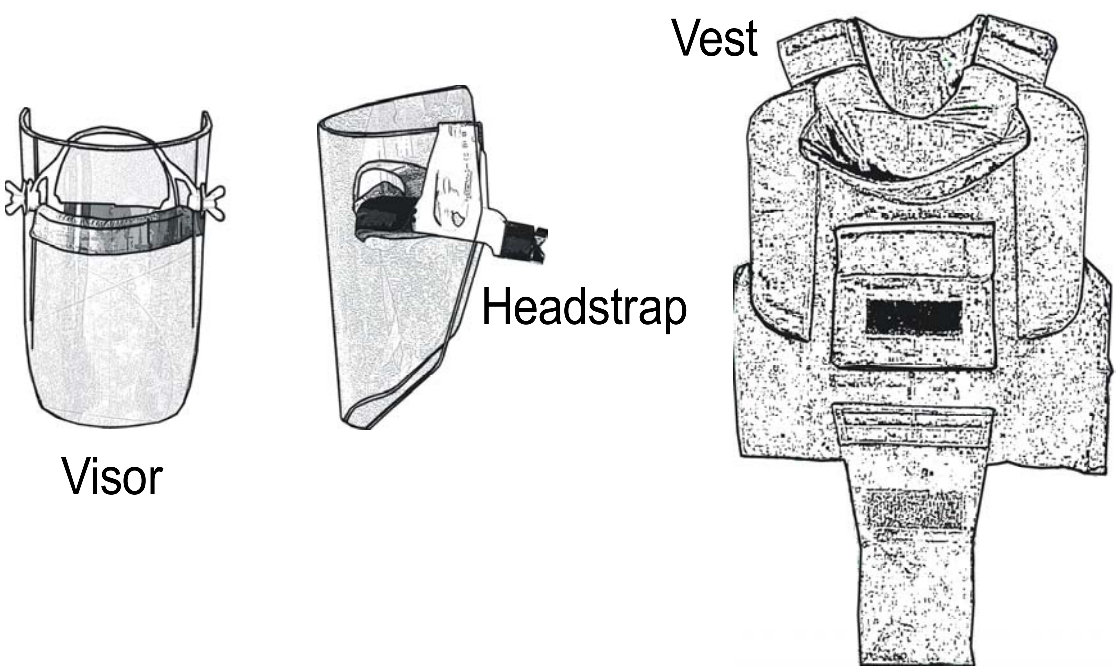

Figure 11: PPE 2

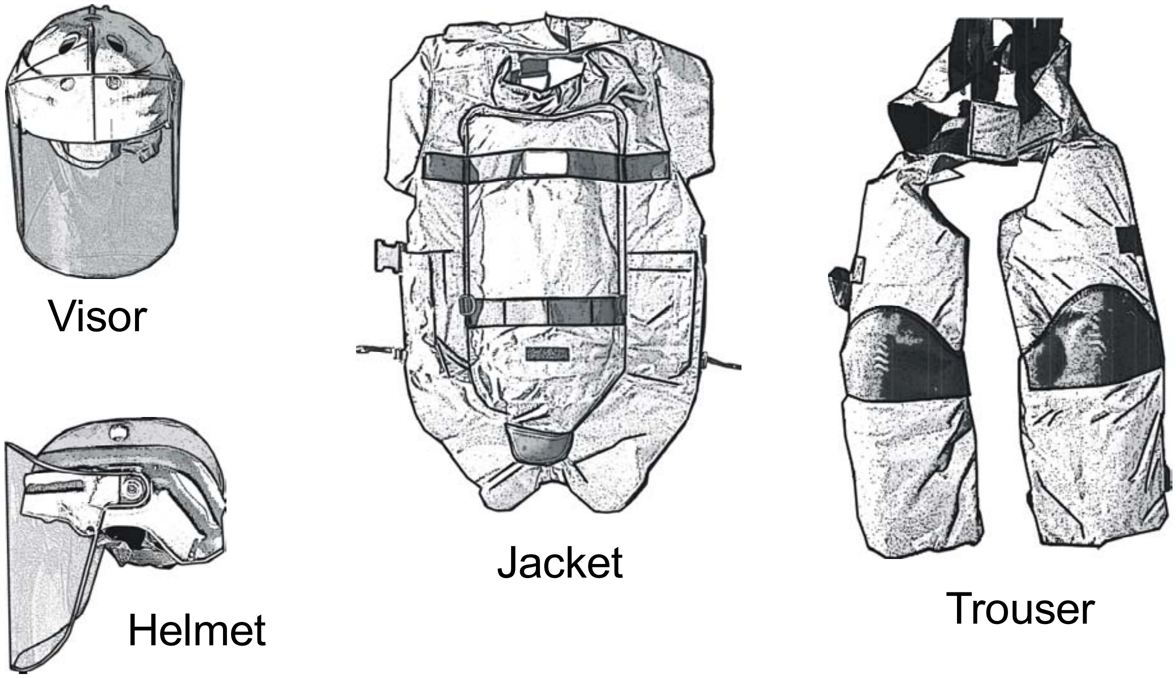

Figure 12: PPE 3

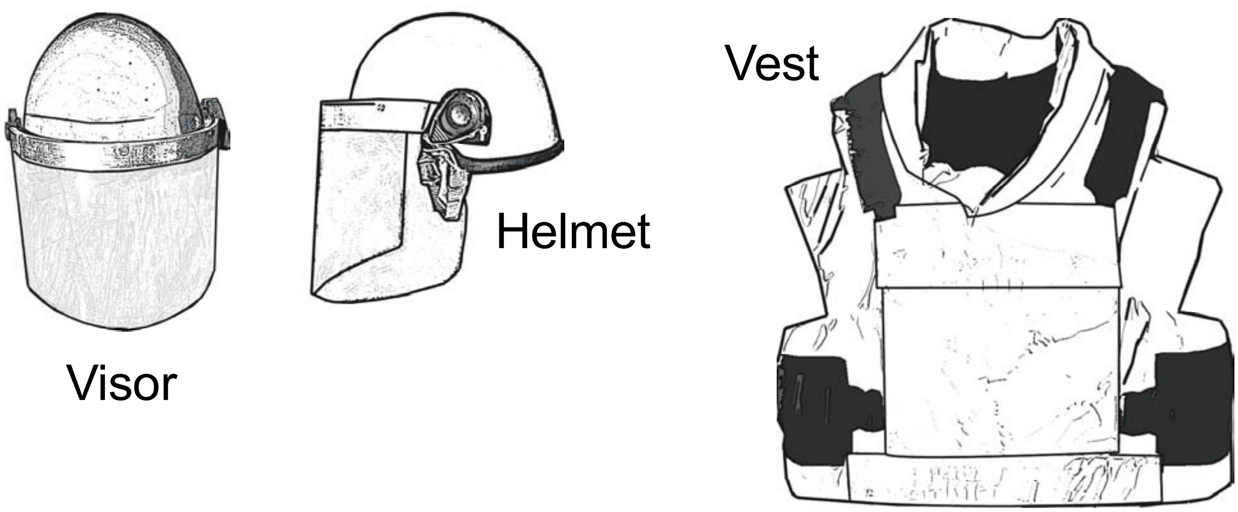

Figure 13: PPE 4

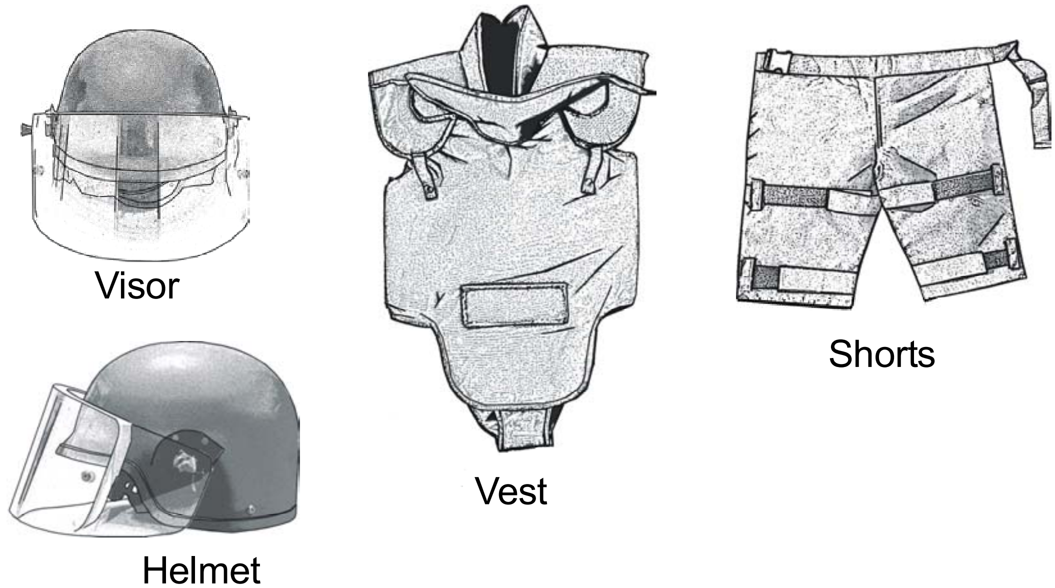

Figure 14: PPE 5

Suit	Suit 1	Suit 2	Suit 3	Suit 4	Suit 5
Body Armor Weight (kg)	2.6	3.2	4.1 body	4.0	4.5 body
			3.6 legs		1.7 legs
Helmet/Visor Weight (kg)	1.0	0.77	1.3	2.6	2.4
Total Suit Weight (kg)	3.6	4.0	9.0	6.6	8.5

Table 3: Suit Weights

Post-shot damage assessment was conducted immediately following the shot and initial safety period. The initial damage assessment included photographic documentation; inspection of suit, dummy, and instrumentation; and preliminary evaluation of acquired data. The dummies were dressed in woven cotton trousers and shirts beneath the PPE to enable detection of fragmentation penetration. Each piece of PPE was thoroughly examined for tearing, fragment penetration or partial penetration, and overall integrity. Damaged PPE components were replaced as required; helmets and visors were replaced every shot. Detailed damage assessments from each shot are presented in Appendix D.

2.3 Mines

Modeling the mine blast itself is a complicated issue. Nominally identical mines may have widely different behavior, and blast characteristics may change considerably depending on soil and environmental conditions. Also, real mines may be difficult to obtain in quantity and to handle safely. To develop an objective test procedure, a test condition should be realistic yet repeatable, a balance that limits the number of tests and cost necessary to effectively characterize the performance of protective equipment. This suggests that mines should be simulated with a relatively well-characterized plastic explosive and should be implanted in a well-characterized soil. Several blast energies may be used to simulate the range of energies expected with actual mines.

In this study antipersonnel landmines were simulated using 50, 100, and 200 grams of C-4 packed in plastic containers that simulate deployed landmines as shown in Figure 15. The simulated mines were selected to best represent effects of the broad spectrum of actual antipersonnel mines worldwide and to provide better repeatability from test to test [Bergeron-2000]. The simulated mines were statically detonated using two layers of DETA sheet and a high voltage RP-80 detonator. The mine molds were provided by Night Vision Laboratories (NVL) and were packed with C-4 and assembled by Aberdeen Test Center (ATC). The weights of C-4 and DETA sheet for each simulated mine were recorded on each data collection sheet. A commonly used antipersonnel mine, PMN, was used on 10 shots for comparison as shown in Figure 16. The PMN mines were statically detonated with a booster composed of C-4 and DETA sheet (RDX based explosive) and an RP-80 detonator.

To provide a repeatable and well-characterized environment for the mine blast, a 61 cm x 61 cm x 61 cm steel open top box was placed within the base of the positioning apparatus in front of the dummy and was filled with medium-grain building sand. The mines were buried 2 cm below the surface of the sand and were statically detonated. Damaged sand was removed after each shot and replaced. For efficiency, two shots were set up and fired simultaneously throughout the test series.

To assess mine performance relative to an actual mine, tests were performed using a statically detonated PMN mines and the simulated mines. A free field pressure sensor was used to record the pressure time history of the blast at a location 124 (± 1) cm horizontally from the center of the mine at the level of the ear as shown in Figure 17. Except for the 50 g mine, each condition had large numbers of mine shots and relatively small spreads in both pressure peaks and integrated impulse. In addition, pressure peaks and integrated impulse were statistically different between the three levels of simulated mine. Further, both pressure peak and impulse from the 200 g mine were very similar to the PMN mine, suggesting similar free field behavior for the actual and the simulated mines. These results give an initial indication of robustness of response, repeatability, and differentiation between three levels of charge.

One significant effect of the confinement of the blast by the soil in both the simulated mine and the PMN mine is the existence of a 'blast cone' as seen clearly in Figure 9 [c.f. Bergeron-2000]. This is a conical region above the mine in which the blast ejecta and streaming flow is substantially more forceful than outside this region. This blast cone makes the effect of position of the dummy in the field extremely important. Further discussion of the physical effects of mine performance within the blast cone is reported below.

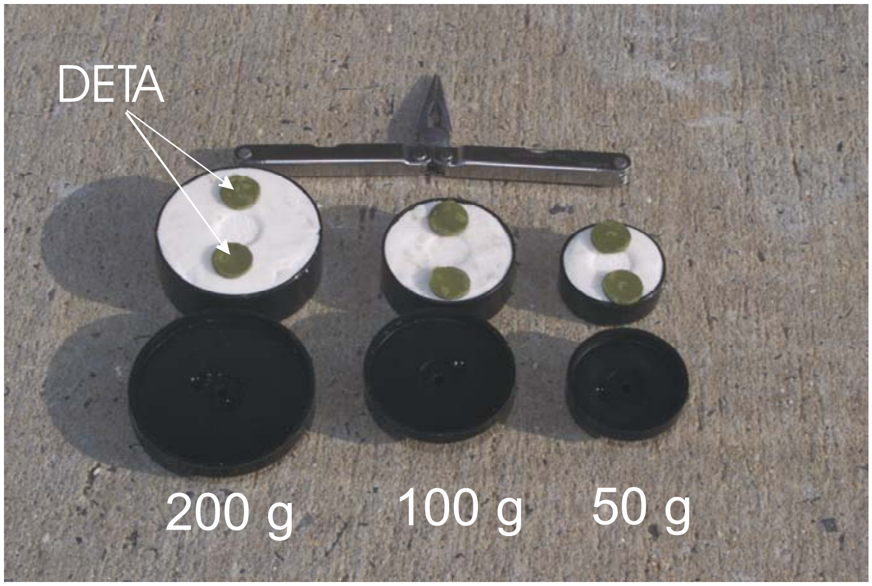

Figure 15: Simulated Mines

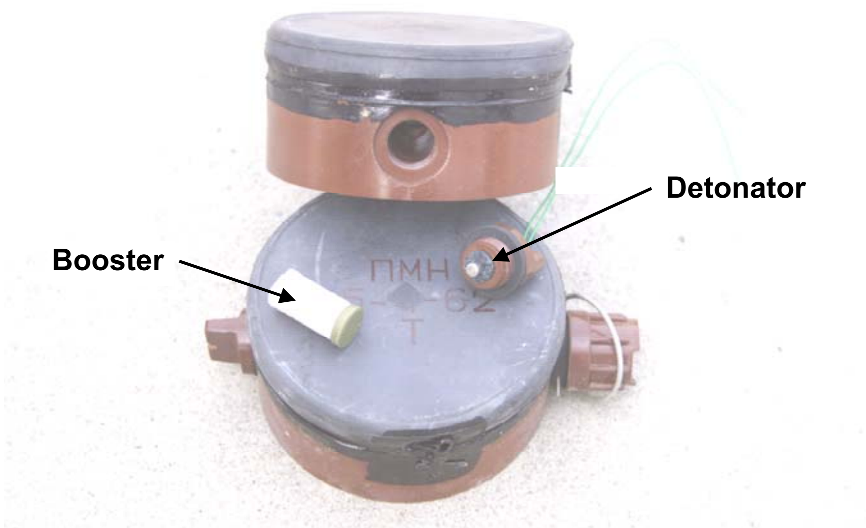

Figure 16: PMN Mine

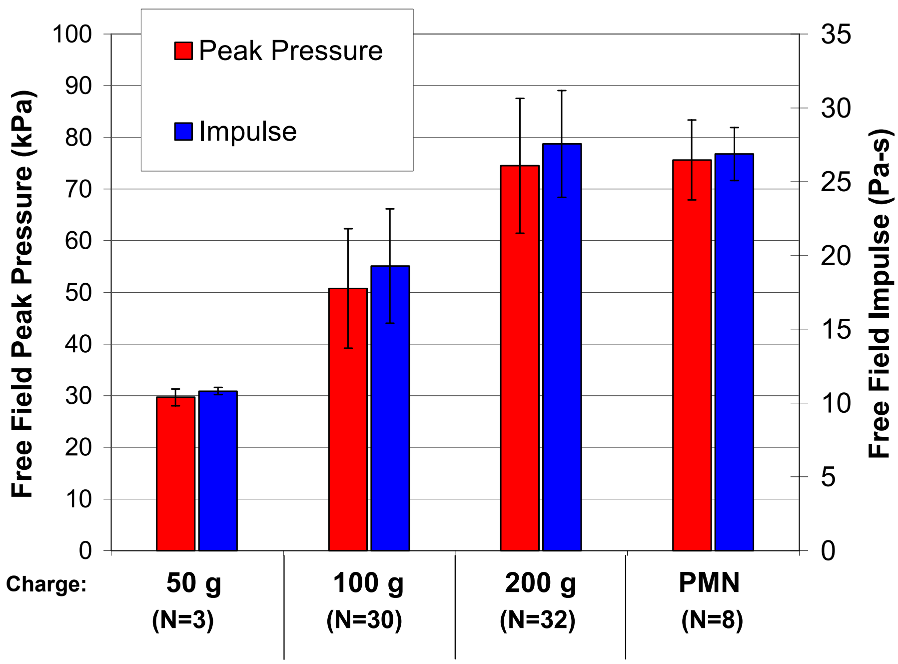

Figure 17: Peak Pressure and Impulse from Reference Pressure Gauge

2.4 Dummies, Test Fixture, and Positioning

Dummies

Two pedestrian version 50th percentile male Hybrid III anthropomorphic dummies (A) and (B) were used in this test series. Both Hybrid III dummies used a Hybrid III head/neck complex mounted on a standard Hybrid III upper neck load cell. The Hybrid III 50th percentile male is shown in Figure 18. A Hybrid III 5th percentile female dummy was used in selected shots (6A through 6D) to represent the deminers from around the world with a smaller body build. The dummies were placed in each of two positions, kneeling and prone. Owing to variations in dummy response with temperature, the internal temperature of each dummy was monitored, and the dummies were stored in a temperature-controlled environment at approximately 72°F overnight and on non-test days.

The Hybrid III dummy was selected for this test series because new development of biofidelic surrogates can be extraordinarily expensive. The Hybrid III series is widely used in the automobile industry for evaluation of the effects of blunt trauma on humans, so there are preexisting injury criteria that may be appropriate in evaluating injuries from mine blasts. In addition, the dummies are relatively inexpensive and robust for repeated impacts.

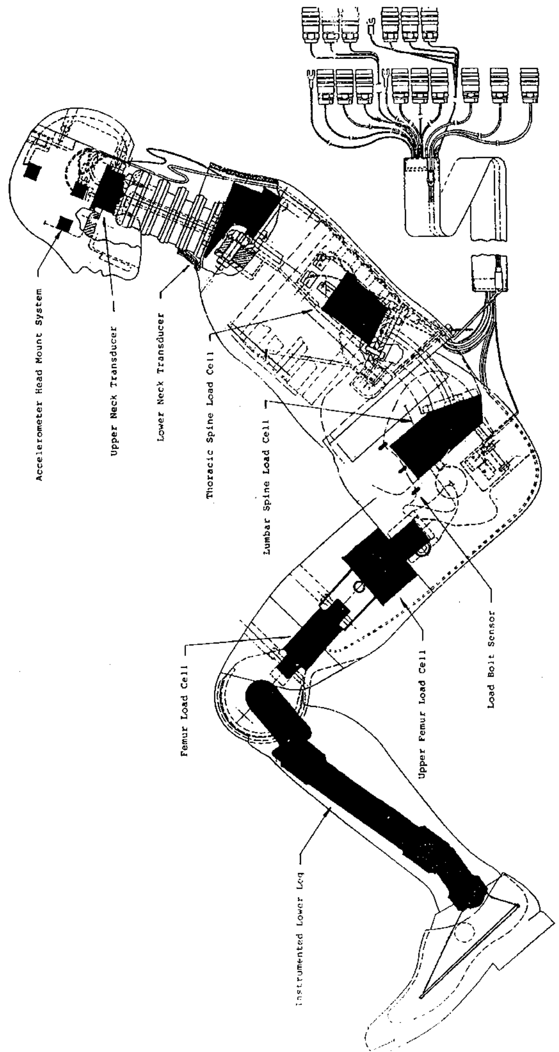

Figure 18: Hybrid III Dummy.

Test Fixture

The test was conducted at the main front Barricade 3 Test Site at Aberdeen Test Center as shown in Figure 20. Two blast resistant positioning fixtures as drawn in Figure 19 were used to support and to position the dummies and were placed at least 4 meters from the wall and from each other to prevent blast interference. These positioning fixtures were developed by a U.S.-Canadian collaboration including U.S. Army CECOM, Canadian Center for Mine Action Technologies (CCMAT), U.S. Army Aberdeen Test Center (ATC), and the University of Virginia. They allow accurate positioning for each shot to within ± 3 mm of reference locations in each spatial axis.

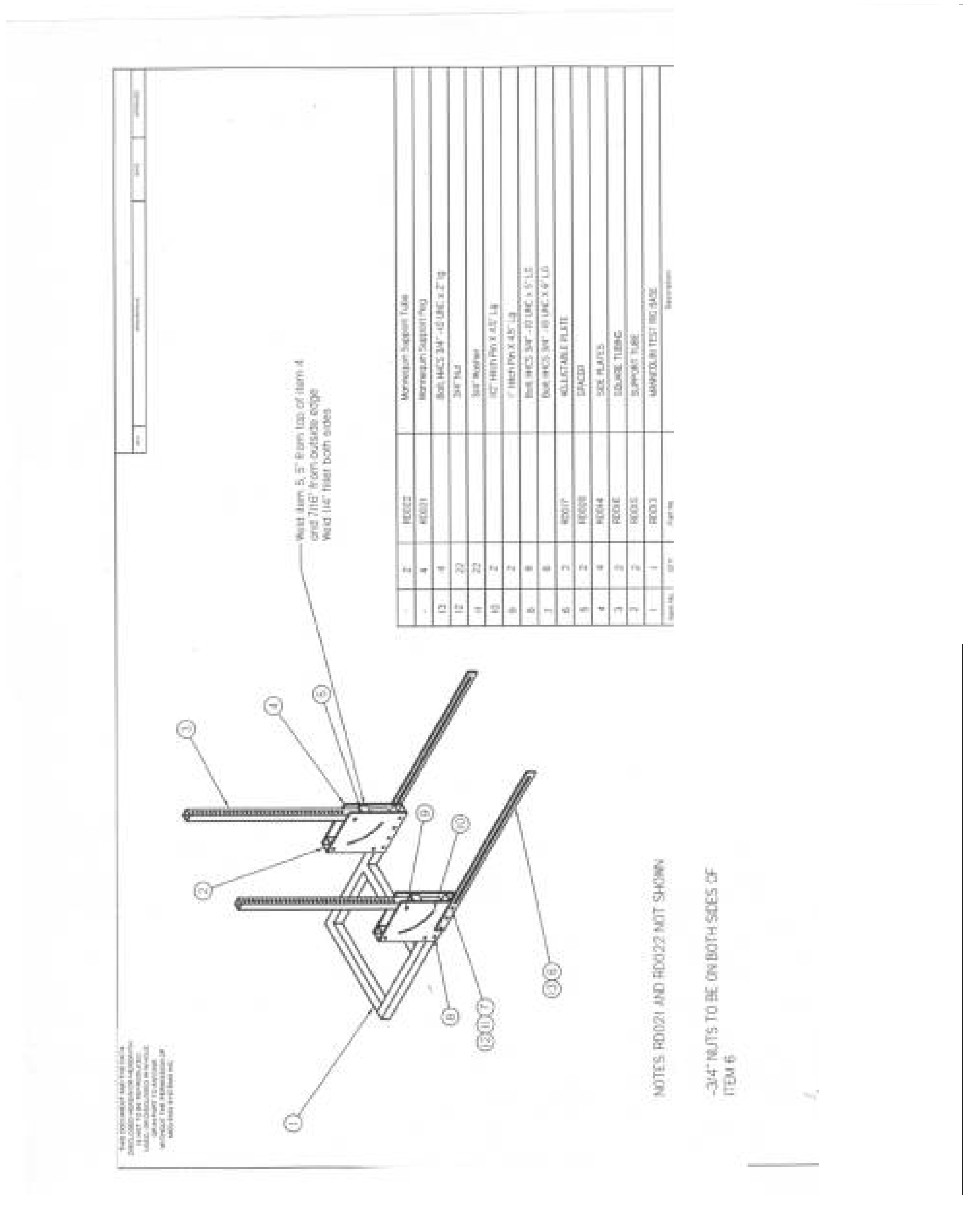

Figure 19: Positioning Fixture Drawing

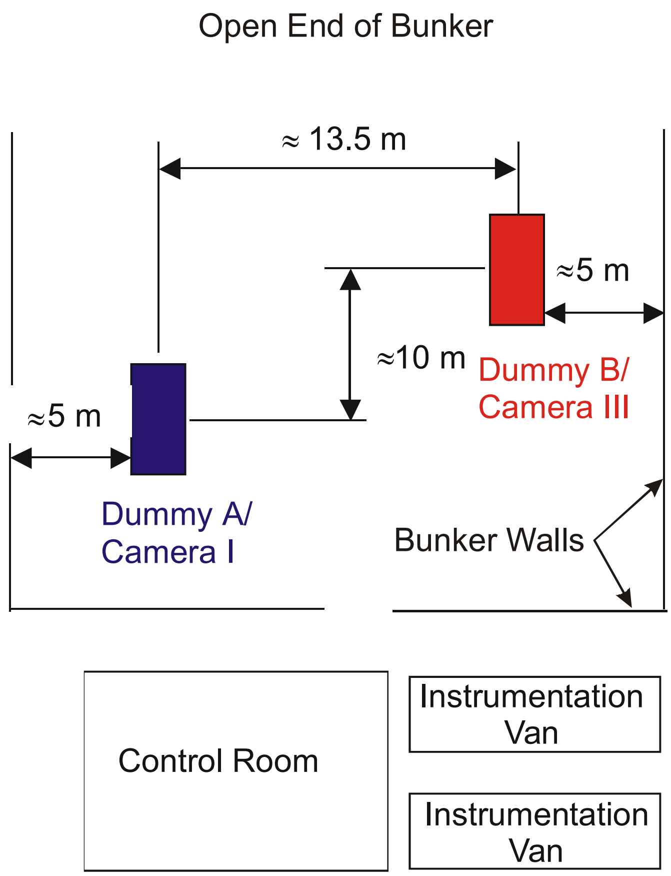

Figure 20: Barricade 3 Test Site Plan View

Dummy Positioning

Accurate positioning is crucial to ensure repeatability of response and to allow an effective evaluation of the performance of a demining PPE for two principal reasons. First, the strength of the mine blast falls rapidly with distance from the mine in the near field. Second, soil confinement of the mine blast imposes a 'blast cone' which includes the most forceful, streaming component of the blast. The test fixture constructed for this study is based on a design produced by a U.S. – Canadian collaboration reported by Nerenberg et al [Nerenberg-2001] used in previous PPE testing as shown in Figure 21.

Accurate positioning of the dummy relative to the center of the mine was performed using a measurement fixture, also shown in Figure 21 for the kneeling position, that allows repeatable positioning of both the mine and the dummy to within approximately ±3 mm of fixed reference points. The measurement fixture incorporated two sliding measurement arms to locate the reference points at the dummy nose and sternum center in a rectangular coordinate system with the origin at the center of the mine with an accuracy of approximately ±1 mm. To ensure accurate mine placement relative to the test fixture, a cylindrical form on the base of the measurement unit was used to create a hole in the sand for mine placement. The form fit inside a sleeve, which remained for mine placement when the measurement fixture was removed. After the mine was placed in the sleeve, the sleeve was removed, and the mine was covered with 2 cm

of sand (flush with the side rails of the positioning fixture). Three forms with matching sleeves were used, one for each simulated mine size. The largest simulated mine size matched the PMN mine.

Both the kneeling and the prone positions were selected to establish a baseline position that was severe enough to produce a significant risk of injury in the unprotected dummy, but not too severe that the dummy could be damaged or that the most protective of the PPEs could not reduce the injury criteria values. The nominal kneeling position, evaluated using an accurate three-dimensional contouring tool, is shown in Figure 23. The dummy was positioned using chains attached to the upper spine, which allow free motion to the rear under a mine blast. The dummy maintains lower extremity position using normal joint friction. After positioning the unprotected dummy in the kneeling or prone position, the measurement fixture was used to record distances from the center of the mine. For the dressed tests, after the nose and sternum were set in place, the dummy was dressed in the PPE. The body armor and visor were then set to selected distances from the mine. For the kneeling position, the radial nose-to-mine distance was set to 70 cm at an angle 65^0 from the mine with x (horizontal) and z (vertical) coordinates as shown in Table 4. The radial sternum-to-mine distance was set at 64 cm with coordinates shown in Table 4.

	Nose to center of mine distance		**Mid sternum to center of mine distance**		**Nose to Mine Angle (from Horizontal)**
Position	**X (cm)**	**Z (cm)**	**X (cm)**	**Z (cm)**	
Kneeling	63.4	29.6	42.2	48.7	65^0
Prone	30.5	33.2	NM	19	48^0

Table 4: Coordinates for Reference Positions Tested (NM = Not Measured)

For the prone position shown in Figure 22, the positioning fixture is not used. Instead, the dummy is balanced on the elbows, and position is maintained by normal joint friction. To produce potentially injurious head accelerations in the unprotected dummy, the radial distance is significantly decreased to 45 cm, at an angle of 48^0 vertically from the mine. Coordinates are shown in Table 4. For several preliminary shots, additional kneeling and prone positions were tested as shown in Appendix A.

The Hybrid III dummy was modified to increase the range of motion in both the lower cervical spine and the lower lumbar spine to enable the dummy to assume a realistic prone position with approximate biofidelic spine extension. Human range of motion in extension is approximately 35 degrees in the lumbar spine, approximately 25 degrees in the thorax, and approximately 50 degrees in the neck. Since the Hybrid III dummy has a limited number of locations to add additional extension, a 30 degree wedge was inserted above the flexible lumbar spine. In addition, the slot in the adjustable lower neck mount was elongated to allow a total of 22.5 degrees in extension from the neutral position. Use of these adjustments produced an approximately realistic Hybrid III dummy prone position as shown in Figure 22. Drawings and photos of these mounts are shown in Appendix B.

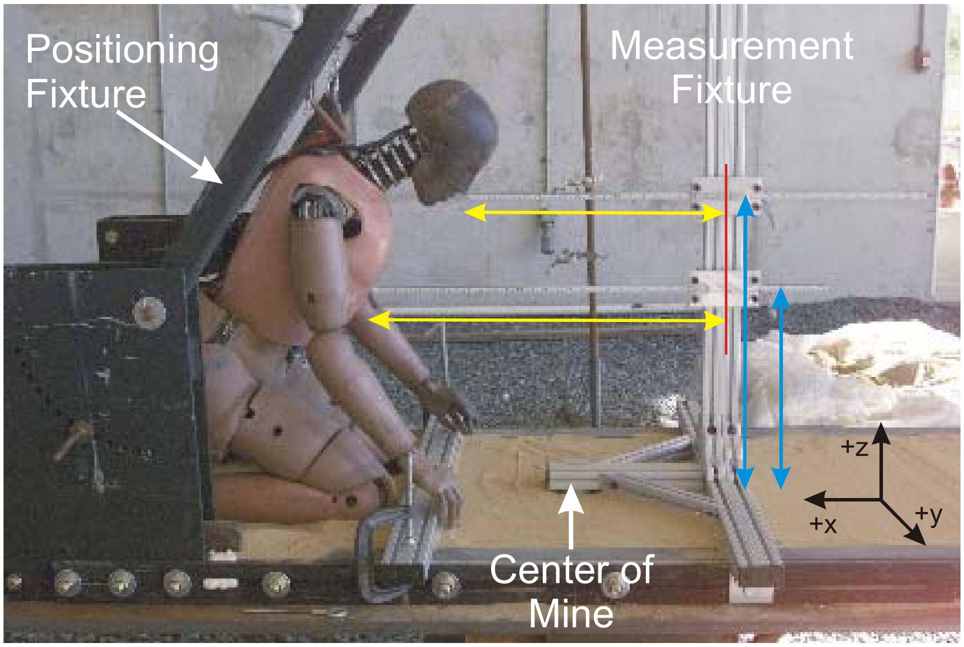

Figure 21: Kneeling Dummy with Positioning and Measuring Fixtures

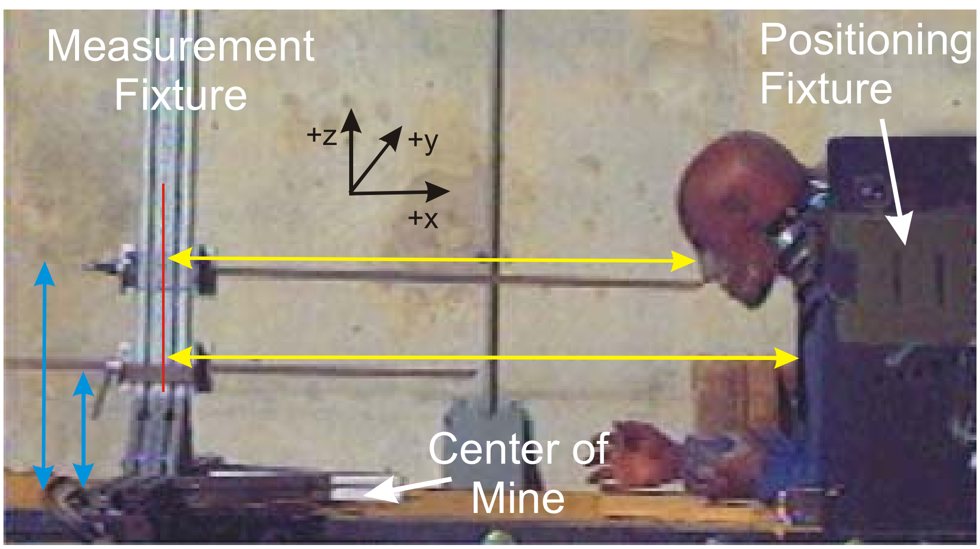

Figure 22: Prone Dummy with Positioning and Measuring Fixtures (Note: Positioning Fixture Not Used for the Prone Position)

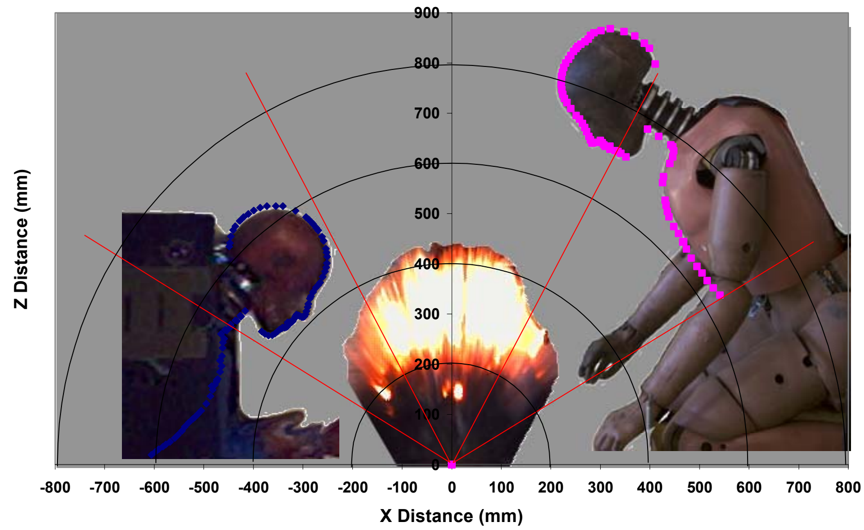

Figure 23: Nominal Kneeling and Prone Positions Relative to the Center of the Mine - Radial Lines at 30^0 and 60^0

2.5 Instrumentation and Data Acquisition

Hybrid III anthropomorphic dummies were instrumented to measure temperature, pressure, sternum acceleration, neck moments and forces, and acceleration in the head and chest as shown in Table 5. Triaxial acceleration data were collected at head and chest locations. Upper neck load cells measured forces and moments in the x, y, and z axes from frontal, lateral, or combined impacts. Also, pressure sensors were used in the thorax and head to determine the risk of blast injuries to the lungs and ears. For the first few shots, thermocouple sensors were embedded in a skin simulant constructed of urea formaldehyde (Beetle) molded resin and attached to the dummies' skin on the hand to determine risk of burn injuries (as shown in Figure 24.). The technique showed that at all explosive levels, no sensor signal exceeded the burn injury threshold and was not used for the remainder of the test series. For all signals, the sampling frequency was 200 kHz with antialiasing filtering at 40 kHz. After each shot, sensors were inspected for damage and were replaced as required.

Transducer	Location	Data Collected	Notes
Accelerometer	Head CG	Triaxial acceleration	Endevco 7270A-6k
	Chest CG	Triaxial acceleration	Endevco 7270A-6k
Load Cell	Upper neck	M_x, M_y, M_z and F_x, F_y, F_z	Frontal, lateral, or combined impacts.
Accelerometers	Sternum	Acceleration	Chest acceleration Endevco 7270A-6k
Displacement Transducer	Sternum	Displacement in x	Chest deflection.
Pressure Transducer	Thorax: skin surface, between 3rd and 4th rib	Pressure-frontal impact and side on	Kulite XCQ-093-500A Kulite LQ-125-500A
	Head, skin surface, mounted laterally at ear location	Pressure	Kulite XCQ-093-500A
Thermocouple in Skin Simulant Figure 24	1 each, thorax, head, hand	Temperature	Omega 0.5 mil and Omega 3 mil bare wire gages.
Pressure Gauges	Free field at the same x y locations as ear and thorax	Pressure	PCB 102-A04
Thermocouple	Spine box	Internal temperature	Static

Table 5: Instrumentation

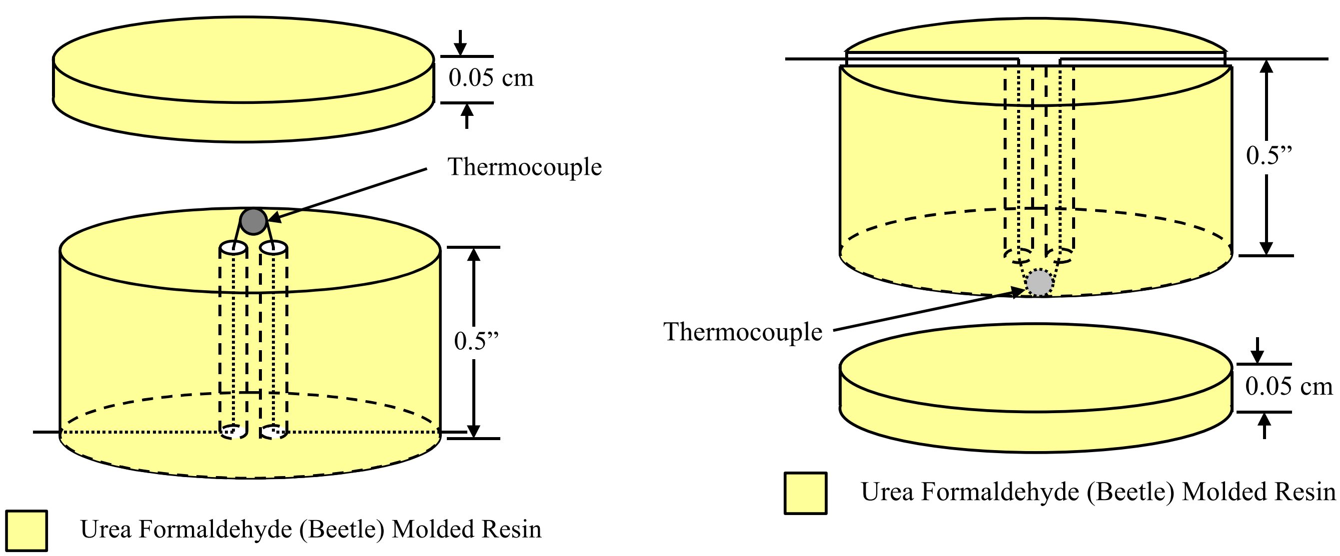

Figure 24: Skin Simulant with Embedded Thermocouple

2.6 Photography

Two high-speed video cameras, a Kodak 4540 and a Kodak HG 2000, were used to document blast evolution and dummy response during each shot. The Kodak 4540 black and white video camera recording rate was set to 9000 frames per second (fps) while the HG 2000 video camera recording rate was 1000 fps . Pre- and post-test still photographs were taken to record the test setup and to document all PPE and dummy damage.

3. Injury Criteria and Dummy Response

Sensor data from the mine blasts into the unprotected dummies was examined for repeatability and dummy-to-dummy variation. This includes tests both with and without a PPE. The principal areas reported below are head blunt trauma, neck blunt trauma, thoracic blunt trauma, and burns. A key issue in the evaluation of the blunt injury data is whether the standard injury criteria for the Hybrid III dummies may be successfully used since the dynamic time scale of the blast is different than that of automobile crashes.

To provide effective simulation of injuries actually received in mine blast incidents, the types of injuries evaluated should be blunt head trauma, blunt neck trauma, blunt thorax trauma, blast lung, blast-induced hearing damage, and burns. Blunt injuries can also evaluate the potential for 'fall' type injuries caused by whole body displacement from blasts, though no whole body displacements were seen in this test series owing to the stiffness of the Hybrid III dummy.

In subsequent subsections, the evaluation of injuries using dummy surrogates is discussed. This discussion includes the presentation of results under these simulated mine blasts using relevant injury criteria appropriate for use with the Hybrid III dummies.

3.1 Overview and PPE Fragment Performance

The blast event was generally short compared to the usual durations of impact events for the Hybrid III dummies. The pressure response of the blast was completed in a duration much shorter than a ms, with acceleration response being approximately 1 ms or greater. As the simulated and PMN mines are not fragmentation mines, the PPEs were not expected to undergo substantial penetrations. The PMN mines did produce fragments from the detonation mechanism and large pieces of the bakelite containers. However, no penetrations resulted from this fragmentation. There was only one full penetration of the face shield with PPE 2 in Shot6D, and no complete penetrations of the body armor during the test series. However, many visors completely separated from the head during the blast event, while this may be protective for blast mines, separation may not be desirable for protection against fragmentation mines. Full descriptions of the fragment protection of each PPE suit in this test series are reported in Appendix D.

3.2 Head Blunt Trauma Injuries

As shown in the field data above, fatalities from head injuries are very significant in mine blasts. These injuries may be caused by direct blast impingement on the head, or by blunt trauma from impingement of the protective gear. One injury criterion commonly used with the Hybrid III dummy head/neck complex is the Head Impact Criterion (HIC) for concussive head injury [Versace-1971] based on the Wayne State Concussive Tolerance Curve [Patrick-1963]. HIC includes the effect of acceleration time history $a(t)$ and the duration of the acceleration. HIC is defined as:

$$HIC = \left\{ (t_2 - t_1) \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} \right\}_{\max}$$

where t_1 and t_2 are the initial and final times (in seconds) of the interval during which HIC attains a maximum value. So, HIC includes the effect of head acceleration and duration; when the acceleration is expressed in g's, a HIC value of 1000 is specified as the level for onset of severe head injury. The maximum time duration of HIC is limited to a specific value, usually 15 ms. Physically, HIC predicts that large accelerations may be tolerated for short times and is evaluated using the head triaxial accelerometer at the head center of gravity. This standard is often used to assess head injury using Hybrid III dummies in frontal impacts. However, HIC is based on human cadaver and animal impact data with durations that are usually 5 milliseconds or greater, with extremely limited data less than 1 millisecond in duration. The acceleration effects of near field blasts are often shorter than 5 milliseconds, raising serious questions about the applicability of the usual injury criteria to mine blast head trauma.

Head Injury – Unprotected Dummy

HIC values obtained for unprotected, kneeling dummies are shown in Figure 25 for mine blast strengths of 50 g C-4, 100 g C-4, and 200 g C-4. These HIC values for repeated tests show good repeatability among charge sizes and excellent correlation between Dummy A and Dummy B. In subsequent analysis, sensor data from these dummies are lumped. The differences in HIC between charge sizes are statistically significant ($p < 0.01$) with increasing response for increasing charge size. Kneeling and prone conditions were selected to produce roughly equivalent head response for an unprotected dummy. However, the prone position is approximately 25 cm closer to the center of the mine.

For the usual 1650 Hz filter used with acceleration time histories that are components of HIC, only the 200 g simulated mine tests show a high risk of head injury for the unprotected Hybrid III 50^{th} % male dummy. However, if a 10,000 Hz filter is used as shown in Figure 26, the HIC values increase so that all test conditions now see significantly injurious HIC values well above 1000. This contrast arises since most of the HIC durations were around 1 millisecond as shown in Figure 27. This implies that the basic frequency of the blast event is 1000 Hz or higher. So, the relationship between HIC and actual physical injury for these rapid tests can only be roughly estimated. Thus it is necessary to establish a physical injury model for high rate blunt trauma and correlate it to the dummy model.

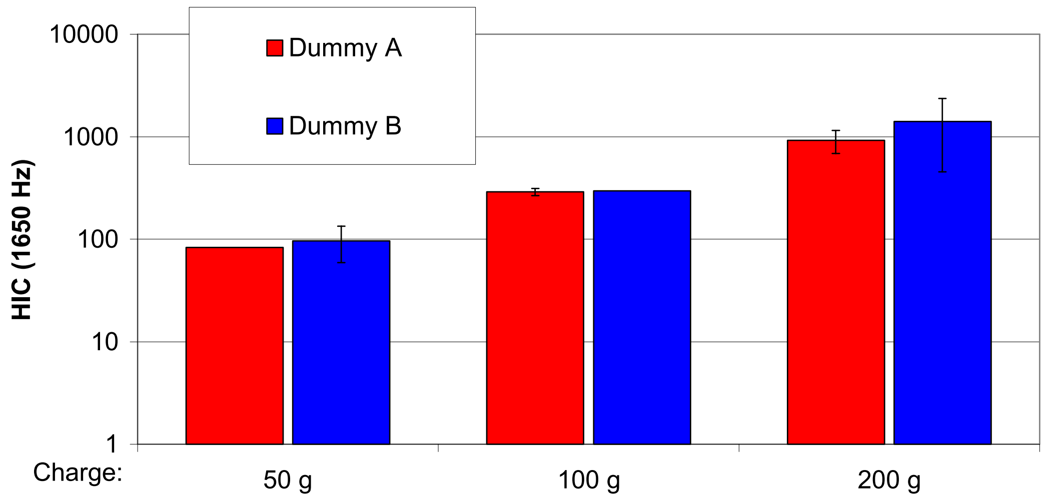

Figure 25: Variation of HIC (1650 Hz) with Unprotected Hybrid III 50th % Male Dummies in the Kneeling Position (Average Values for Repeated Testing)

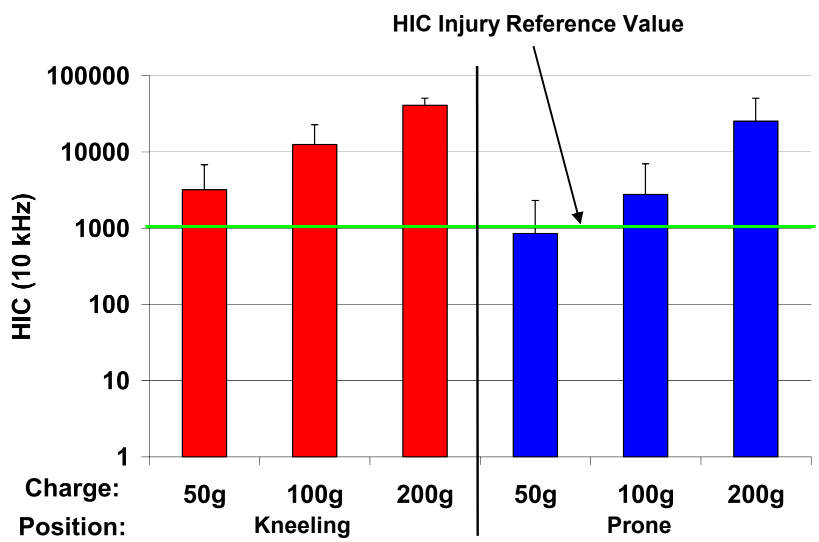

Figure 26: Variation of HIC (10,000 Hz) with Unprotected Hybrid III 50th % Male Dummies in the Kneeling and Prone Positions (Average Values for Repeated Testing)

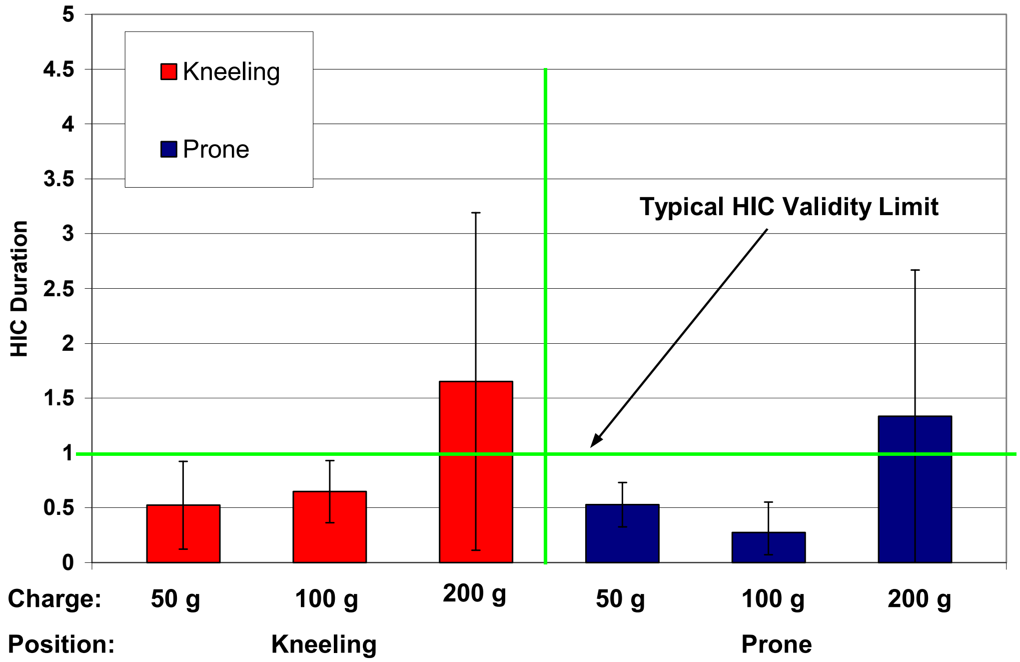

Figure 27: Variation of HIC Duration for Unprotected Hybrid III 50th % Male Dummies in the Kneeling and Prone Positions (Average Values for Repeated Testing)

Head Injury – Suited Dummy

HIC values for the tests using kneeling dummies are presented in Figure 28. As expected, the addition of a PPE helmet to an unprotected dummy improved protection from head trauma for some of the PPEs tested. Helmets 4 and 5 performed well for both the 100 g and 200 g simulated mines. The helmet of PPE 3 decreased HIC statistically significantly for the 100g charge only. Similar trends are seen with the PMN mines and the simulated mines.

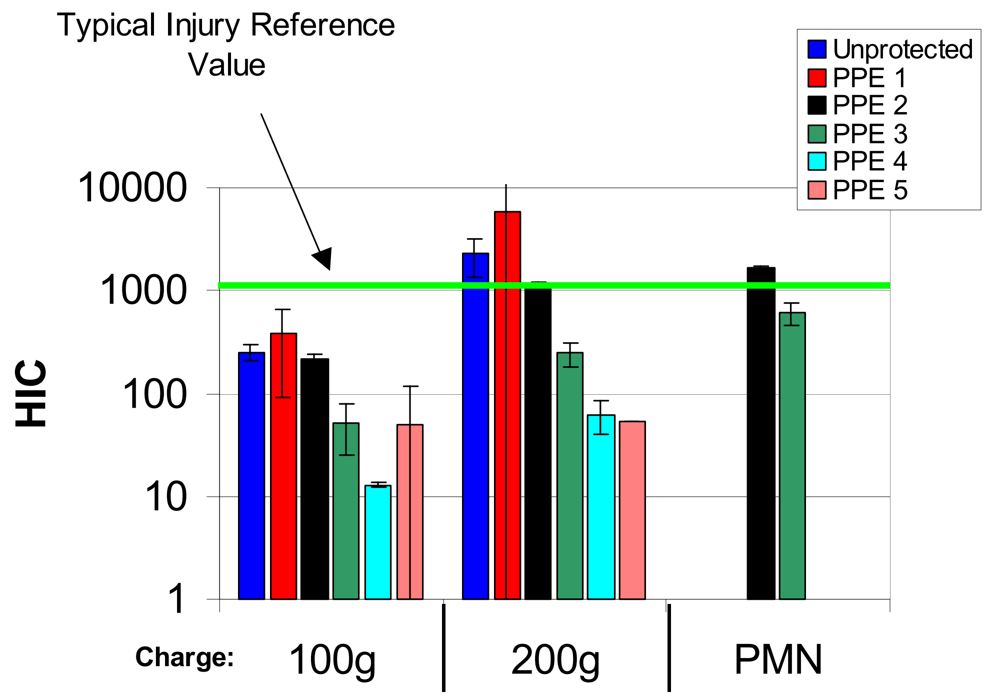

Figure 28: HIC Values for Mine Blast into Kneeling Dummy, All Charge Sizes, All PPEs

Unexpectedly, the facial protection with PPE 1 did not reduce the risk of head blunt trauma when compared to the unprotected case. The physical features of the head protection gear, including the projected frontal area and the mass (Figure 29) provide an explanation for the substantial increase in HIC values from the unprotected dummy to a dummy protected by PPE 1. First, the heavier helmet/visor sets produced lower HIC values. The two heaviest helmets, those from PPE 4 and PPE 5, performed better than those from the other PPEs for dummies in the kneeling position because the larger mass decreases the acceleration of the head, resulting in a smaller HIC value. The mass of the standard Hybrid III head/neck complex is 5.8 kg. So, the 2.6 kg mass of the helmet/visor set from PPE 5 adds approximately 45% more weight to the structure, and probably explains the significant drop in HIC when suit 5 armor is added to an unprotected dummy.

There is, however, an obvious tradeoff for the protective value of added helmet mass. Increasing the helmet mass without regard for ergonomic factors of wearability of large head supported masses and heating may result in limited usage of the face protection. Second, larger frontal areas of the helmet/visor sets tended to increase the risk of head injury from mine blasts. This frontal area dependence arises from the increased exposure to the blast flow; the larger visors can 'catch' more of the blast wave and induce larger head accelerations.

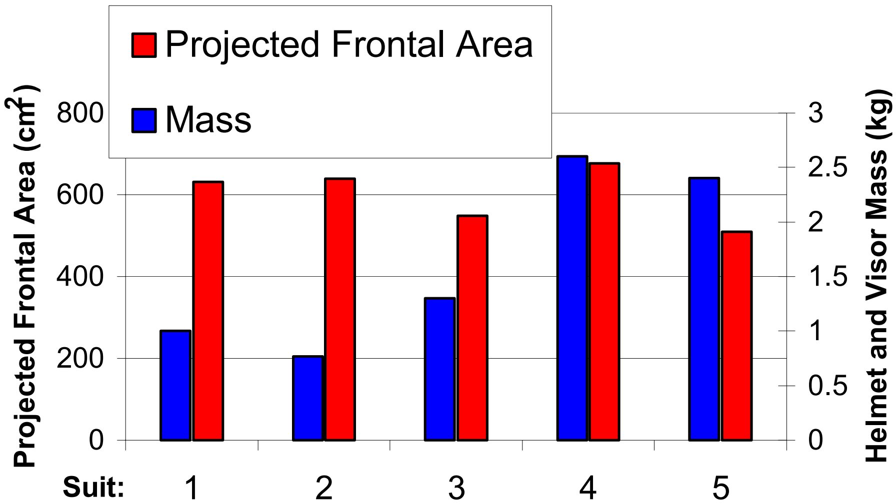

Figure 29: Helmet and Visor Characteristics

Figure 30 presents the results for dummies in the prone position. Only PPE 5 reduced the HIC for the 200 g charge when compared to the unprotected values. In all other cases HIC was not significantly different. Geometric differences between the prone position and the kneeling position produce this difference in injury risk. The head in the prone position is more upright than in the kneeling position, so the blast streams more tangentially to the surface of the visor. This decreases the effect of frontal surface area on the HIC value. However, there is still some evidence of a mass effect as the PPE with larger helmet masses still has lower risk of blunt trauma injury.

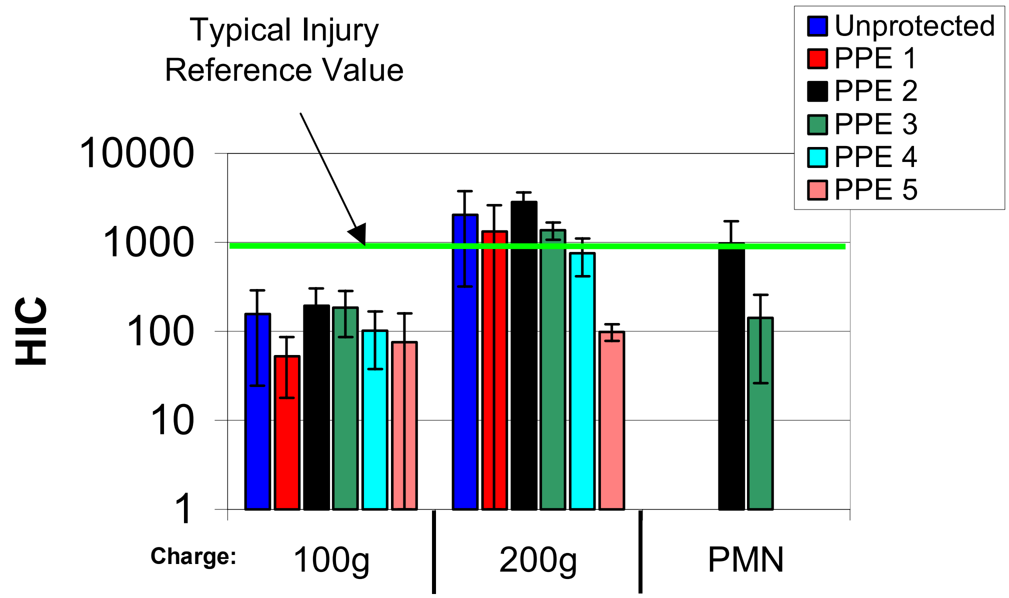

Figure 30: HIC Values for Mine Blast into Prone Dummy,
All Charge Sizes, All PPEs

To further quantify the relationship between the helmet mass, projected frontal area, and HIC, the HIC values were plotted against the helmet parameters and linear curve fits were applied to the data. Four different data sets were considered: kneeling position, 100g charge; kneeling position, 200g charge; prone position, 100g charge; and prone position, 200g charge. Each data set had a separate linear curve fit.

The HIC values were plotted against the nondimensional area/mass (cm^2/kg) ratio for each PPE helmet and the linear curve fits were determined for the four data sets as shown in Figure 31. The helmet area is nondimensionalized by the frontal area of a Hybrid III dummy head, and the head/helmet mass is nondimensionalized by the mass of a Hybrid III dummy head. This ratio of frontal area to mass was chosen because the acceleration of a head under blast pressure loading is directly related to the frontal projected area of the head or helmet, and acceleration under an applied external force is inversely related to the mass of the head/helmet. The average R^2 for these fits varied from 0.08 (P100) to 0.79 (K200). It was easy to distinguish between the 200g and 100g charges on this plot, as the 200g charge data (both kneeling and prone) had much larger slopes than the 100g charge data.

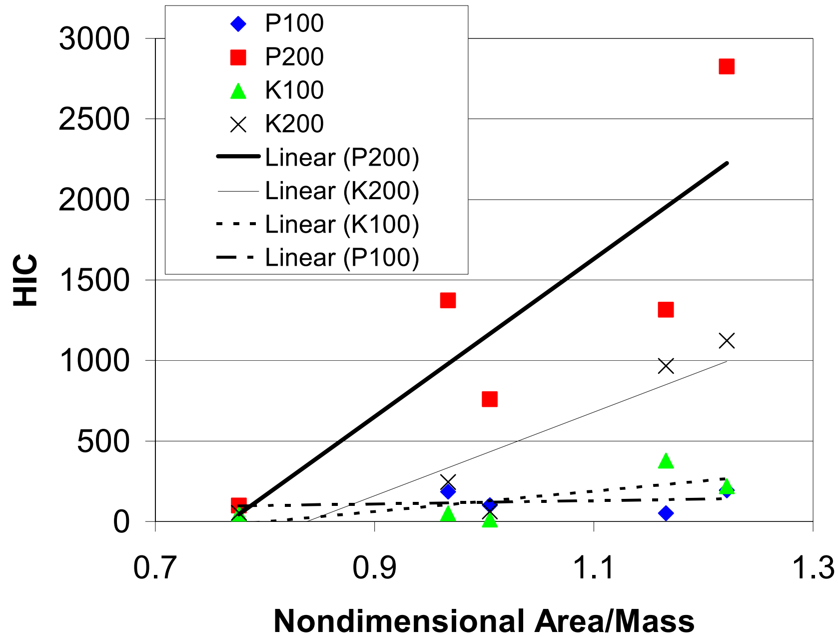

Figure 31: Variation of HIC with Helmet Frontal Area/Helmet Mass for Simulated Mines of 100 g and 200 g (K = Kneeling, P = Prone)

3.3 Neck Blunt Trauma Injuries

Neck injuries from blasts are possible owing to different rates of acceleration of the head and of the chest under blast loading. Physical trauma to the neck may be evaluated using the neck force transducers that may be incorporated into the Hybrid III dummy. Barring local damage to the neck itself, the dynamic impulse in the neck must be transmitted through the relative motion of the head and the chest. This transmission of force is relatively slow compared to the impact of the blast wave. So, neck injuries in blast are similar in rate to impact neck injuries that have been studied in automobile safety and other contexts. There is a proposed neck injury criterion promulgated by the National Highway Traffic Safety Administration (NHTSA) termed the N_{ij} criteria [Eppinger-2000]. The criterion is to be used with Hybrid III dummies.

The N_{ij} criterion is a composite injury indicator based on a linear combination of neck loads and moments. These loads include neck axial tension and compression, and the moments include neck flexion and extension. The postulated injury levels for these combined loads have been validated using human cadaver, volunteer, and animal subjects. N_{ij} is defined as

$$N_{ij} = \frac{F_Z}{F_{INT}} + \frac{M_Z}{M_{INT}}$$

where F_z is the tension/compression force and M_z is the flexion/extension moment. The values F_{INT} and M_{INT} are the normalization values for the mode of axial force or bending as shown in Table 6. The hexagonal perimeter in Figure 32 represents the Injury Reference Value (IRV) of N_{ij} = 1.0 that corresponds to a 30% risk of severe neck injury. The shaded portion is considered acceptable neck loading by this criterion.

Intercept Value	Hybrid III 50th % Male	Hybrid III 5th % Female
F_{INT} – Tension (N)	4170	2620
F_{INT} – Compression (N)	4000	2520
M_{INT} – Flexion (N-m)	310	155
M_{INT} – Extension (N-m)	135	67
Peak Tension (N)	6806	4287
Peak Compression (N)	6160	3880

Table 6: Normalized Forces and Moments for N_{ij} Criteria

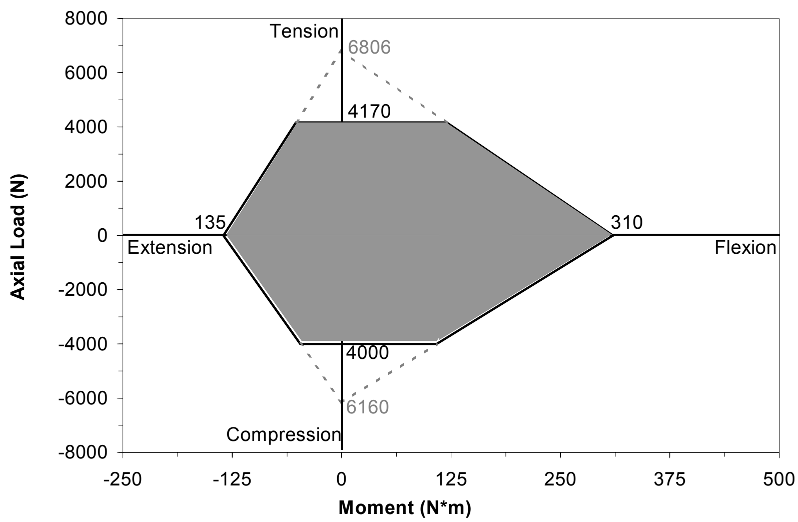

Figure 32: N_{ij} Criteria for the 50th Percentile Male Dummy [Eppinger, 2000]

Neck Injury – Unprotected Dummy

The N_{ij} standard injury predictions were used to assess the effects of the particular dummy used on the test results as shown in Figure 33. Though none of the tests using the unprotected dummies show a high risk of injury indicated by N_{ij} values, there is a significant difference between risk of neck trauma from Dummy A to Dummy B. For matched tests between Dummy A and Dummy B where sufficient tests were available, there was a statistically significant difference between the neck response of the two dummies. The N_{ij} criterion is the sum of the effects of both neck tension/compression axial load and neck flexion/extension moment. However, the configuration of the Hybrid III neck has little axial compliance for loading in tension. For this series of tests, the maximum value of N_{ij} was, on average, a function of 90% neck extension and only 10% tension, and thus, it is highly dependent on the compliance allowed within the neck by the pretensioning setup of the neck.

After the test series was complete, it was determined that the pretensioning bolt supporting the neck for Dummy B was loose, while Dummy A was within specifications. This resulted in a decreased resistance to extension in Dummy B. With a looser neck, Dummy B tended to move out of the blast cone over long times, reorienting the applied load and substantially decreasing

the moment. So, only Dummy A was used in further analysis. As this occurred over relatively long times, this did not affect the head accelerations.

Also seen in Figure 33, N_{ij} levels generally increase with charge size. For all tests the 50 g and 100 g charge sizes are statistically significantly different than the 200 g charge size ($p < 0.01$). The prone N_{ij} values are generally larger than the kneeling for two reasons. First, the prone position is 25 cm closer than the kneeling position to the mine blast, though lower in the blast cone. And second, the orientation of the head in the prone tests is more normal to the local blast flow, producing an increased neck moment. *So, this result should not be taken as an indication that the prone position has a higher risk of neck injury than the kneeling position for the mines tested.*

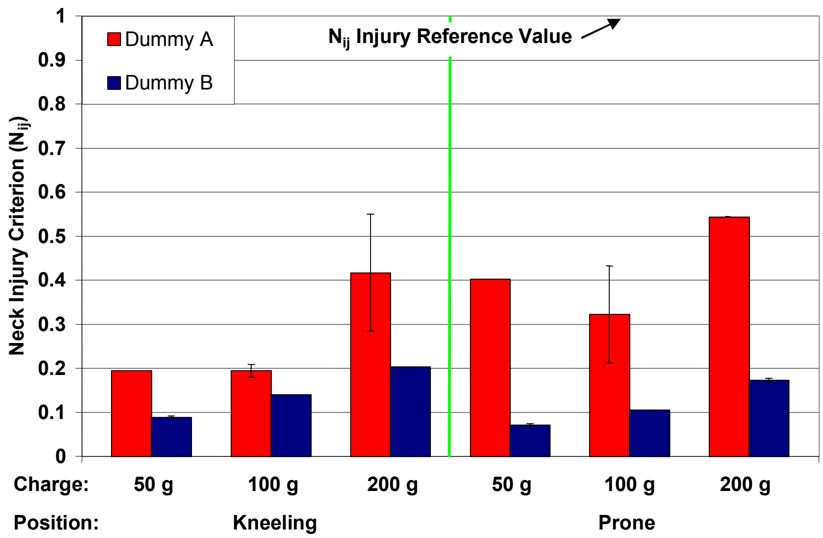

Figure 33: Effect of Dummy for Matched Tests of an Unprotected Hybrid III 50th % Male Dummy In Both Primary Test Positions And At Three Charge Masses

The strong effect of the blast cone can clearly be seen in additional tests performed at varying distances to the mine and at varying angles within the blast cone. For the kneeling position, two angular positions of the head and two nose-to-mine distances were examined as shown in Figure 34 for a 100 g simulated mine. The tip of the nose was used as a reference point for the head position and the two angular positions were 70° and 65° as measured from the horizontal. The vertical distance to the mine, however, remained relatively constant. The 5° reduction in angle shifts the loading distribution away from the thorax towards the head alone, creating higher relative loads on the head. These higher loads produce higher neck flexion moments.

This result directly contradicts the expectation that increasing radial distance from the blast substantially decreases loading. The 70° position had a 65 cm radial nose-to-mine distance, while the 65° position had a 70 cm radial nose-to-mine distance; the increased distance tended to increase the overall loading in this range of angles and distances. This shows the effect of the strongly conical shock, and the importance of evaluating the effects of the blast cone when assessing injury tolerance using this methodology.

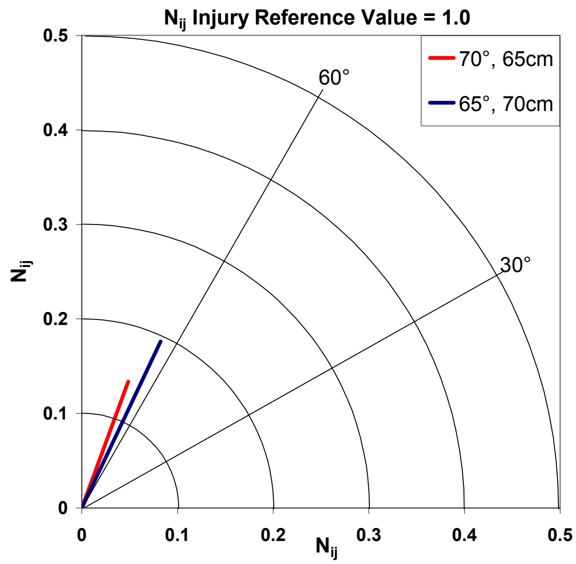

Figure 34: Effect of Dummy Position Relative to the Blast Cone (Kneeling Position, 100-g Charge)

For the prone position with a 200 g simulated mine, three angular positions of the head and three nose-to-mine distances were examined (Figure 35). A constant nose vertical height (33.2 cm) was maintained, and the dummy was moved horizontally relative to the mine position. The tip of the nose was used as a reference for the head and was placed 50 cm, 37.5 cm, and 30.5 cm horizontally from the center of the mine. The reduction in angle for the prone position has a slightly different effect than for the kneeling position. In the prone position there is minimal thoracic loading because of the lower position of the body. Therefore, the reduction in angle simply moves the head further from the conical blast cone, thus reducing the momentum transferred to the head and the neck flexion moment.

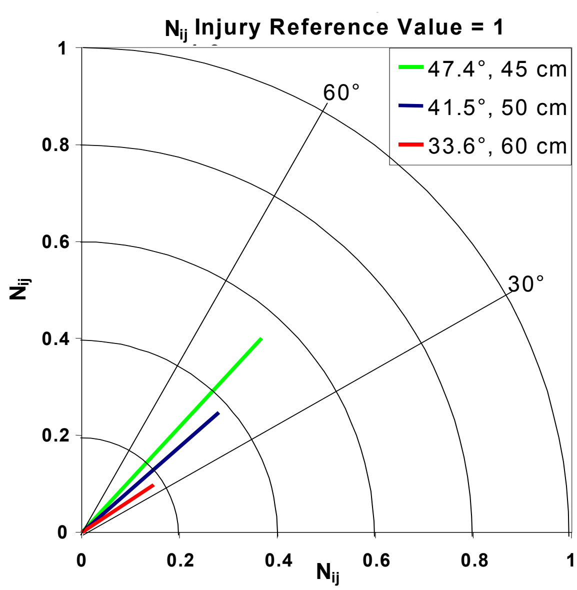

Figure 35: Effect of Dummy Position Relative to the Blast Cone (Prone Position, 200-g Charge)

For all tests conducted, including tests with PPEs, the highest N_{ij} value reported was 0.55, which is well below the 1.0 IRV threshold. So, there is a small risk of serious neck injury for these mine simulants in the positions selected for testing.

Neck Injury – Suited Dummy

One primary focus of this study was the evaluation of commercially available personal protection ensembles for use by humanitarian deminers. Many parameters can influence the effectiveness of the PPEs, including suit/helmet mass, projected area, coverage area, and the position in which they are evaluated. For a larger projected area, a higher momentum transfer from the blast is transmitted to the head. However, the additional mass by the helmet increases the inertial resistance of the head/helmet composite, reducing the acceleration and delaying and reducing the peak force applied. Other variations are a result of the distribution of the projected area of the helmet and faceshield. The higher the projected area is on the head, the farther the resultant force of the blast is from the neck, thus creating a longer moment arm for the loading to act.

Figure 36 and Figure 37 illustrate the trends in suit performance for neck blunt trauma injuries for the various mine charges in both the kneeling and the prone positions. Despite the limited number of reportable tests for the dummy suited with one of the PPEs, it is evident that the average value for N_{ij} for all cases (position and charge) is reduced for the protected dummy. However, some tests did have higher N_{ij} values than the average baseline unprotected dummy. This is seen, for example, in tests using PPE 3 in the prone position with a 100 g charge (Figure 37). So, there is a potential for a lightweight visor or visor/helmet combination to add enough projected area to the dummy head without substantial counterbalancing mass that the N_{ij} values would increase for the protected dummy. However, the highest N_{ij} value reported for all the tests conducted was 0.55, which is well below the 1.0 IRV threshold. With the data resulting in such low N_{ij} values, we can conclude that for this test series, there exists a very small risk of serious (AIS $\geq$ 3) injury.

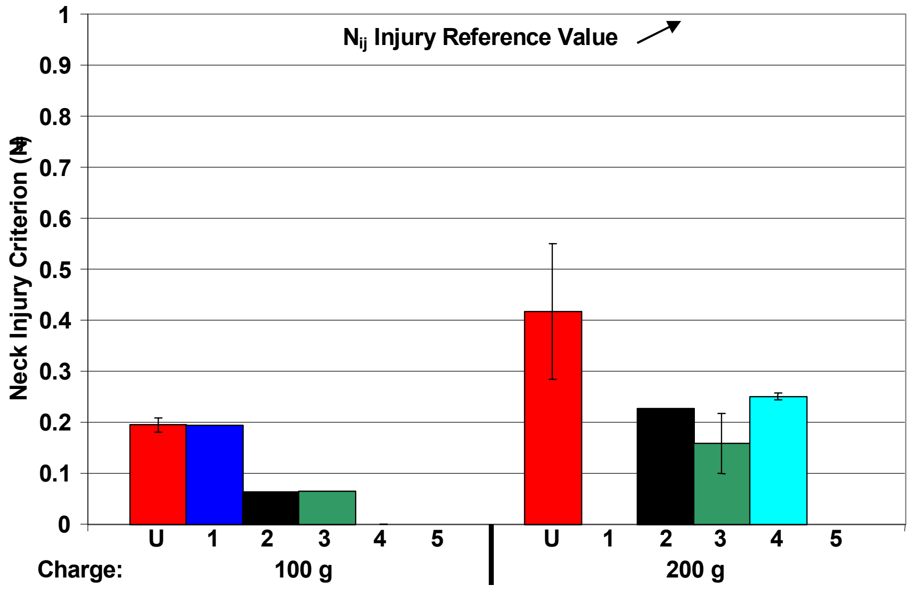

Figure 36: Effect of PPE on neck injury for dummy in the kneeling position

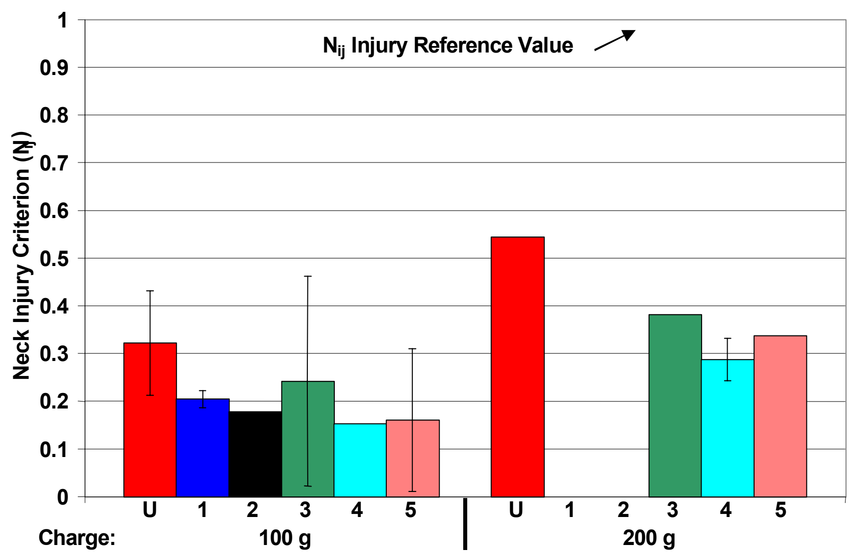

Figure 37: Effects of PPE on neck injury for dummy in the prone position

3.5 Thoracic Blunt Trauma Injuries

The blast pressure waves and following pressure wave from the detonation of a mine have the potential to produce severe blunt trauma to a human thorax in proximity to the blast. Several injury criteria have been developed to characterize the risk of thoracic injury. One widely used criterion, based on maximum displacement of the chest wall, allows a maximum 63-mm chest deflection in the 50th percentile male Hybrid III dummy [Eppinger-2000]. The displacement of the chest wall can be regarded as a surrogate for local strain within the chest. Presumably, the larger the local strain within the chest, the more injurious the local impact.

Another potentially useful injury criterion is the viscous criterion (VC) developed by Viano *et al* [Viano-1988]. This criterion is the product of the velocity of chest wall displacement (V) and the deformation of the chest relative to the initial thickness of the thorax (C). This quantity has been linked with the rate of energy storage in the thorax. A value greater than 1.0 m/s is considered injurious.

Thoracic Blunt Injuries – Unprotected and Protected Dummy

Displacement chest injury criteria were initially used to assess the effects of many of the test parameters including the charge size, dummy position, and suits. The peak chest compression for any of the tests was 2.6 mm, which falls significantly below the IRV for chest compression. The majority of tests produced chest compressions below 1 mm, and the average chest compression for all tests was only 0.6 mm. These small values lead to two conclusions for the test analysis. First, there exists a very low risk of chest injury related to compression. Second, the small compression values are so small that the inherent error of the chest slider mechanism may become significant, thus limiting the statistical trends that may be inferred from the data.

The protective equipment was evaluated relative to the unprotected dummy for both the 100g and 200g charge levels and for both the kneeling and the prone positions (Figure 38 and Figure 39). As discussed earlier, the peak compression values are significantly below accepted IRVs and have the potential to be significantly affected by the compliance in the sensor itself. However, one surprising result is that peak chest displacements for several tests with a suited dummy are higher than those for an unsuited dummy. Therefore it may be concluded that the potential exists that a large profile, low mass thoracic protection suit may actually exacerbate the thoracic loading.

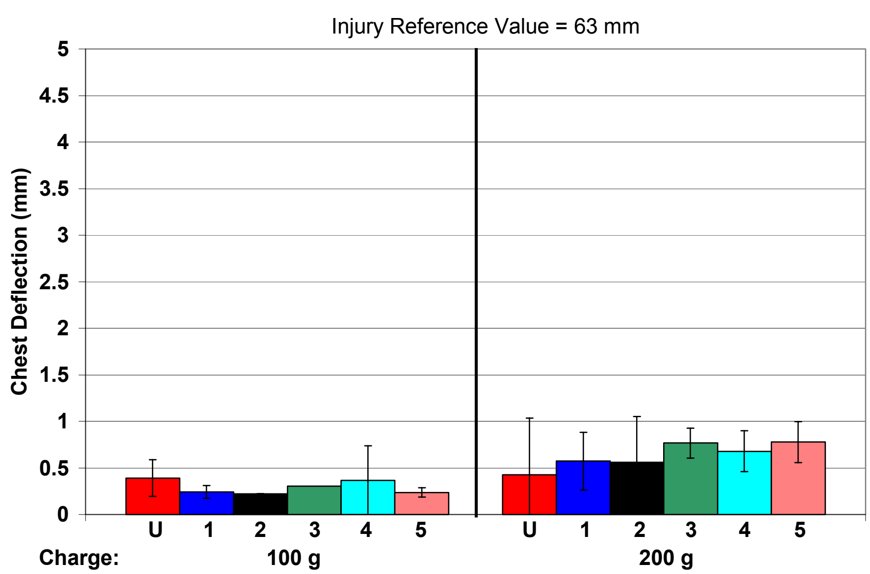

Figure 38: Peak Chest Compression for the Unprotected and Protected Dummy in the Kneeling Position

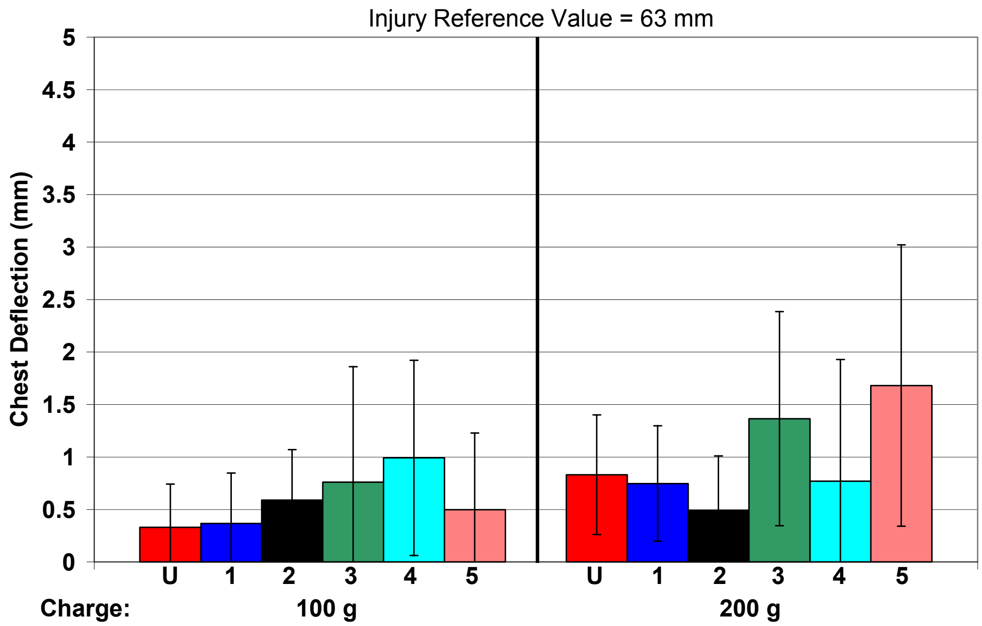

Figure 39: Peak Chest Compression for the Unprotected and Protected Dummy in the Prone Position

For VC, the thoracic displacements are relatively small, and there is no direct measurement of the velocity of the chest. So, the velocity must be calculated either by integrating a sternal accelerometer mounted to the chest wall, or by differentiating the displacement signal. In this test series, the sternal accelerometer was used to obtain the velocity. Though the displacement is small, the velocity is relatively high for this test series. However, the sternal acceleration measurements did not prove robust for this test series. So, the limited numbers of available values for the viscous criterion are shown in Figure 41 for the unprotected dummy. The values generally increase with increasing explosive blast. Statistical comparison of the differences between dummies is unavailable, however, because of the limited data set.

For this test series, the conical blast pattern limited the risk of injury to the thorax. Neither the sternal displacement nor the VC showed values that could be reasonably construed as injurious.

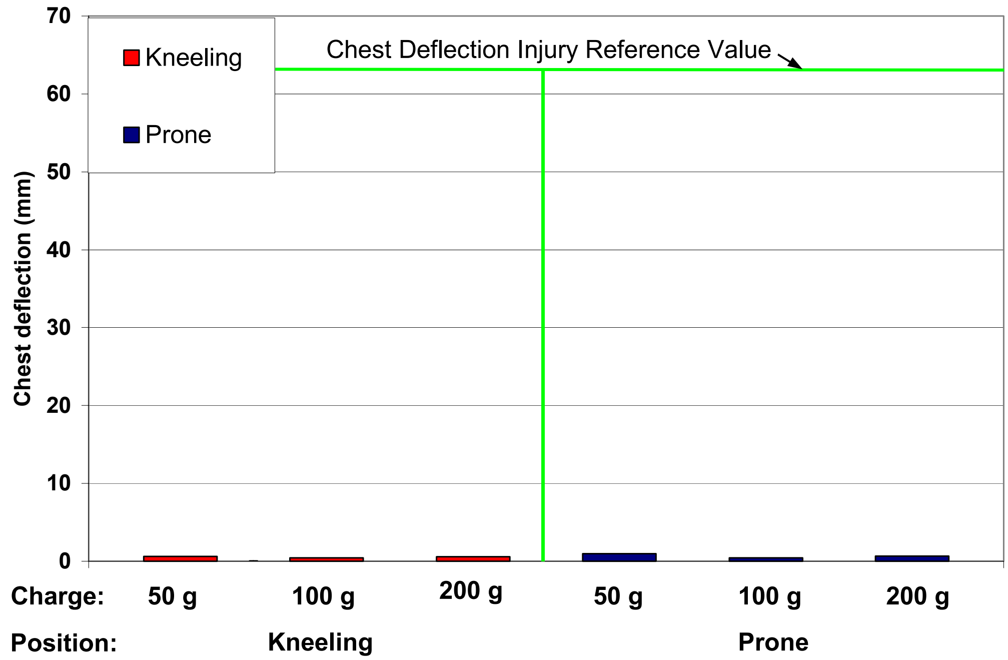

Figure 40: Variation of Chest Maximum VC with Unprotected Hybrid III 50th % Male Dummies in the Kneeling and Prone Positions (Average Values for Repeated Testing)

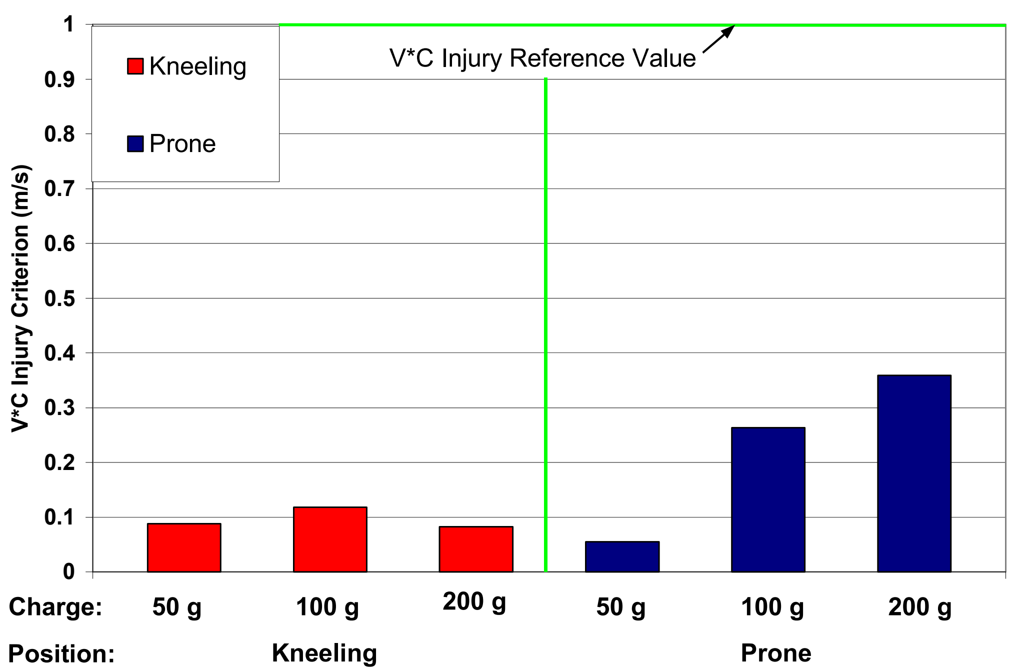

Figure 41: Variation of Viscous Criterion with Unprotected Hybrid III 50th % Male Dummies in the Kneeling and Prone Positions (Average Values for Repeated Testing)

3.6 Thorax and Head Blast Injuries

There is a substantial risk of blast overpressure injuries, either blast lung or blast-induced hearing injuries, close to antipersonnel mine blasts. However, the usual instrumentation of the Hybrid III dummy does not include any assessment of the effects of blast overpressure, either in the head or the chest. So, four pressure sensors were mounted on the surface of the chest to evaluate the potential for blast lung injuries. These sensors were placed in each quadrant of the thorax. In addition, a pressure sensor was mounted in a 'side on' configuration in a hole in the mid-thorax. This pressure sensor had limited success owing to the difficulties of mounting such a gauge in the Hybrid III thorax. Many of the sensor time histories show large peaks that are likely the motion of the gauge in the dummy chest. Finally, a pressure sensor was mounted in the head at the location of the ear to evaluate the potential for hearing damage. Owing to the presence of impulsive spikes in the data in all channels, the pressure data was processed using a 15-point median filter.

The evaluation of blast wave injuries is important since addition of protective equipment for the thorax may exacerbate blast overpressure injuries. Experience using body armor in Northern Ireland has shown an increased incidence of blast lung injuries, either from enhancement of the blast wave behind the body armor or from protection from usually fatal damage [Mellor-1989].

Of the four surface mounted thoracic pressure gauges, the lower gauges failed repeatedly early in the test series. So in the succeeding analysis, the upper right thorax pressure gauge was used. The peak external pressures for the protected and unprotected dummies at the 100 g and 200 g charge level from the upper left thorax gauges are shown in Figure 42. Approximate durations of these pressure time histories are 0.7 ms. These are compared with the threshold lung damage free field values taken from classic work by Bowen *et. al.* [Bowen-1968]. Both the unprotected and protected dummies show much larger peak pressures for the 200 g charge size than the 100 g charge size. In addition, all of the dummies with PPEs show decreased peak pressures relative to the unprotected dummies except PPE 2 for the 200 g charge size. Complex wave interactions behind the PPEs may be the explanation for the large spread in thorax peak pressures for certain PPEs. However, for both the 100 g and 200 g charge sizes, the peak thorax pressure does not exceed the threshold for blast lung injuries. The complexities of evaluating injury criteria for complex pressure waves suggest the strong need for an experimental effort to evaluate such waves in an injury model.

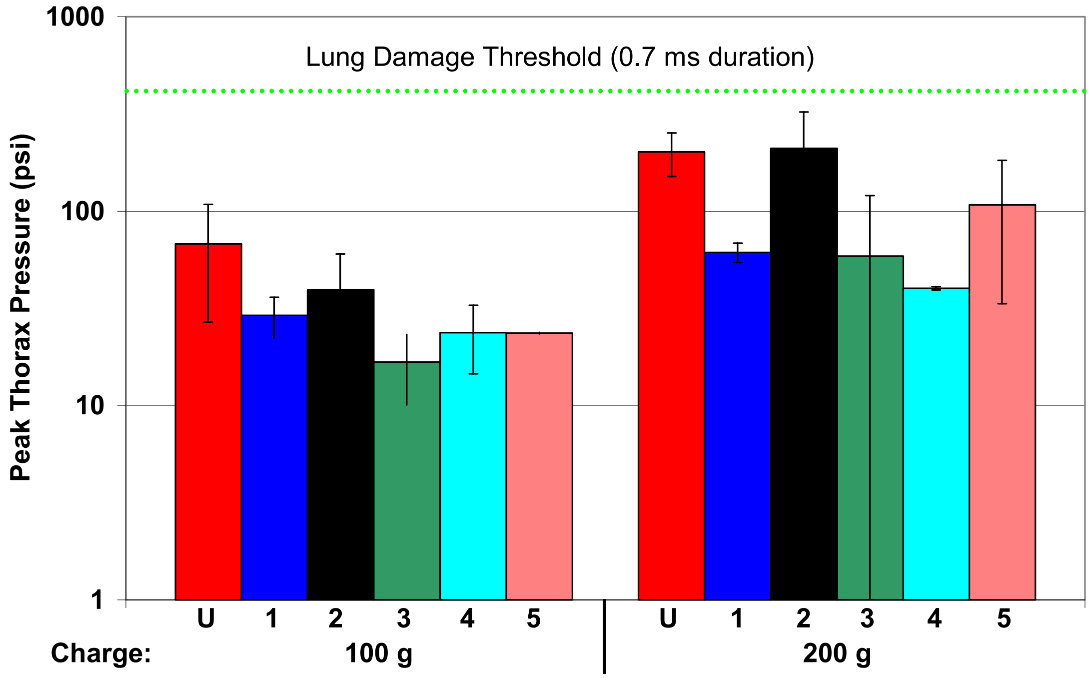

Figure 42: Peak Thorax Pressure for Kneeling Hybrid III 50th % Male Dummies

The peak ear pressures for the kneeling unprotected and protected Hybrid III 50th % male dummy are shown in Figure 43. This measurement is similar to a standard 'side-on' pressure measurement for which injury thresholds are defined. For the unprotected dummy, the pressure profiles are similar to an ideal Friedlander pressure wave (instantaneous rise to peak pressure with an exponential decay) seen in free field blasts. In the protected dummy, there may be streaming flow into the sensor, and there is some evidence of complex flow patterns. These flow patterns complicate the interpretation of the injury thresholds for ear injuries. For the tests in this study, the typical duration of the pressure impulse is approximately 0.7 ms. For the 100 g charge, all of the PPEs show comparable or reduced ear pressure peaks when compared with the unprotected dummy. These peaks are near the threshold for eardrum injury. However, for the 200 g charge, PPE 3 shows greatly reduced ear pressures while PPE 4 and PPE 5 have peak ear pressures that exceed the 50% risk of eardrum injury. One reason for these differences may be that PPE 4 and PPE 5 have relatively large helmets that go over the ears with relatively small visors. This may tend to 'capture' the blast wave under the helmet, increasing the peak pressure.

For the prone position shown in Figure 44, however, both the 100 g and 200 g charge peak pressures for the unprotected dummy are comparable to the peak pressures seen with the PPEs. The reason for the difference between the kneeling and prone results may be the angle of the helmet relative to the blast cone. The prone dummy is substantially lower in the blast cone, and the dummy head is oriented more perpendicularly to the angle of the blast cone. So the contribution from the pressure under the helmet and visor may be minimized.

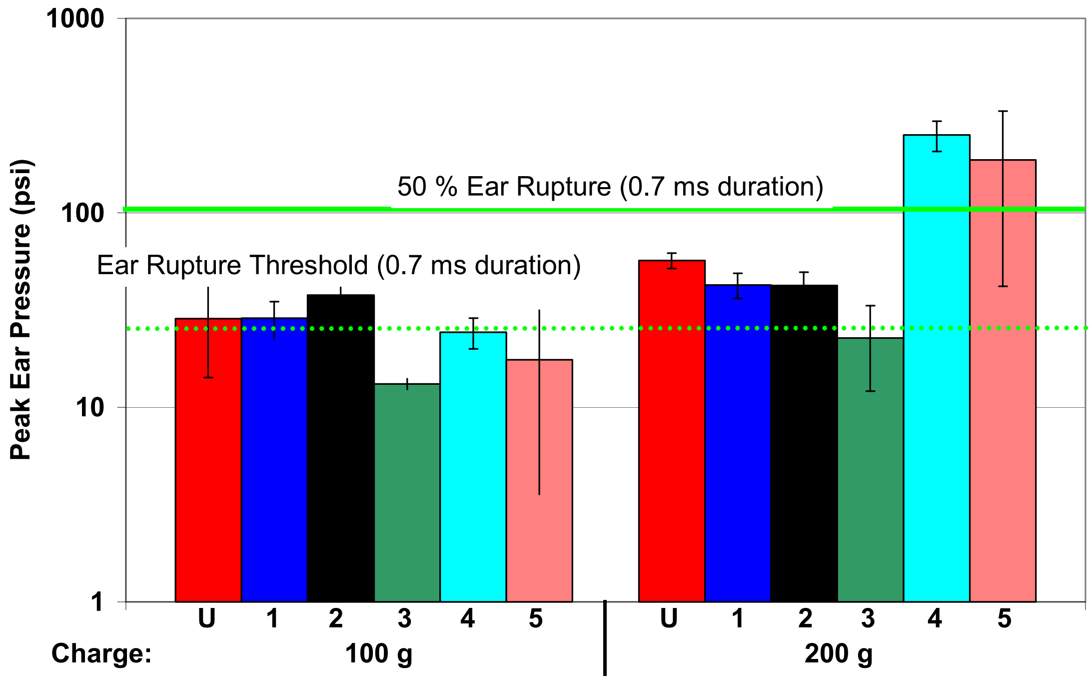

Figure 43: Peak Ear Pressure for Kneeling Hybrid III 50th % Male Dummies

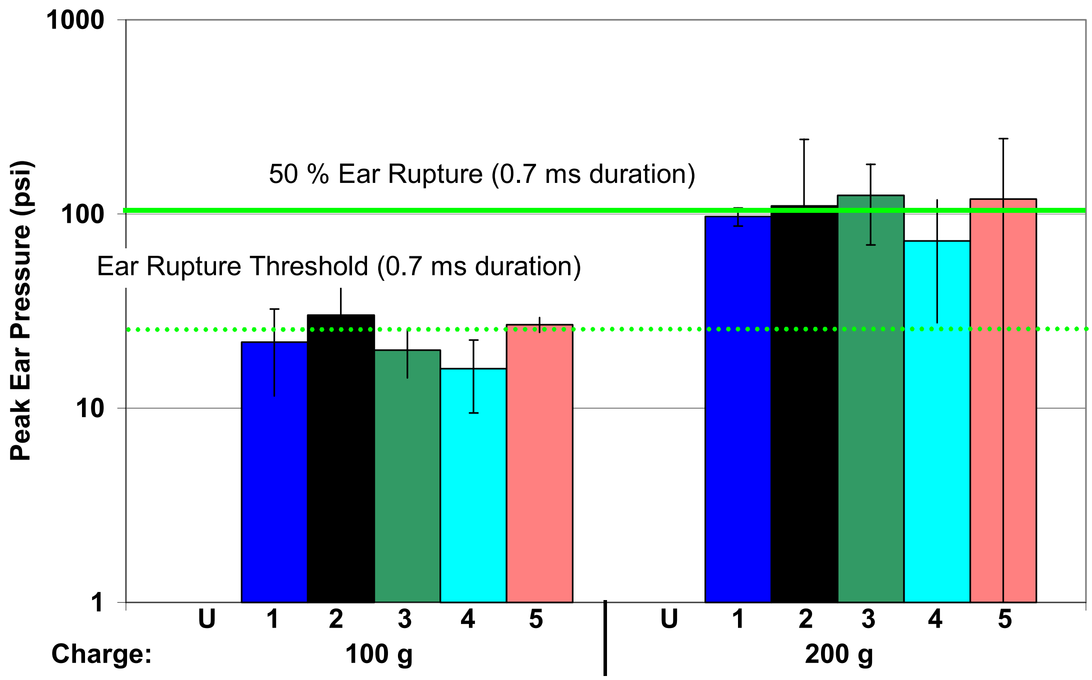

Figure 44: Peak Ear Pressure for Prone Hybrid III 50th % Male Dummies

3.7 Burns

As mine blasts involve explosive deflagration, there is a potential for burns close to mine blasts. The mechanism for this injury is rapid radiant and convective heat transfer into the skin. The timescales for this injury, flash burn, are so short that heat transfer from the skin into the body is limited. This test series used an existing skin simulant for evaluating injuries caused by thermal insults [Derksen-1960]. The technique uses a plastic resin 0.05 cm thick with an embedded thermocouple. The temperature output of the thermocouple was correlated with human injury 120 μm below a living skin surface. Low profile cylindrical samples of this skin simulant with embedded thermocouples were used in this test series to evaluate the risk of flash burns from the blast. These skin simulants were attached to the dummy skin at the chin and on the left hand and were exposed directly to the blast in the unprotected tests.

Blast phenomena may be measured on timescales of milliseconds while most temperature sensors operate on timescales of seconds. To obtain the most rapid temperature sensor response, thermocouple wires of 0.5 mil diameter were used. These wires were fragile for dynamic impact testing, so limited data was collected. The temperature time histories were filtered to 500 Hz to eliminate signals faster than the response time of the thermocouple. These time histories include tests with 4 unprotected hands, including all 3 charge weights used in this series. The chin temperature sensor was used for 9 tests, including 3 unprotected tests at the 100 g and 200 g charge weight, and 6 protected tests using 3 different suits. As there is not sufficient data to differentiate the performance of each suit, they have been lumped together for this analysis.

The induced subcutaneous temperature change in the skin simulant implanted on the dummy hand is shown in Figure 45. This figure includes data from three 100 g tests and a single 200 g test with 42 cm nominal standoff from the mine to the hand. Though the average temperature change induced by the blast is substantially larger for the 200 g charge than for the 100 g charge, both are less than 20 ^{0}C. As the duration of the temperature increase is less than 100 milliseconds in all cases, the risk of injury from severe flash burns to the hand appears to be small. To compare with other widely used injury criteria, a free air temperature of approximately 1100 ^{0}C for a duration of 1000 milliseconds is necessary to produce second-degree burns [Ripple-1990].

The induced subcutaneous temperature change in the skin simulant implanted on the dummy chin is shown in Figure 46. Since the number of tests is limited, there is no differentiation between levels of protection of the chin, and the three helmets used are lumped for the analysis. The dummy chin temperature sensor is located approximately 70 cm radially from the center of the mine in the apparent blast cone. For the unprotected chin, the induced temperature change in the sensor increases substantially with charge size. However, as with the dummy hand, the risk of severe burns appears to be quite small, even with unprotected skin contact from the blast. Interestingly, though the face shield on the protected dummy appears to provide some protection to the chin for the 100 g charge size, the induced temperature change for the 200 g charge size is similar to that seen in the unprotected dummy. This may be the result of loss of the face shield early in the test and a subsequent skin temperature elevation. As the induced temperature differential is likely not injurious for these tests, the loss of the face shield during the blast may have had a limited impact on burn injuries.

The use of the skin simulant with the temperature sensor showed a very small risk of serious flash burns with the explosive and charge sizes used in this testing, even with unprotected skin close to the blast. This was confirmed by the limited burn damage to the dummy skin over a test series of over fourteen unprotected blasts to each dummy head at radial distances as close as 45 cm to the center of the mine. Factors outside this study, however, such as more incendiary explosives, delayed or inefficient combustion, may increase the risk of serious burn injuries in actual mine blasts. Indeed, the depth of burial plays an important role in the amount of afterburn [c.f. Bergeron-1998].

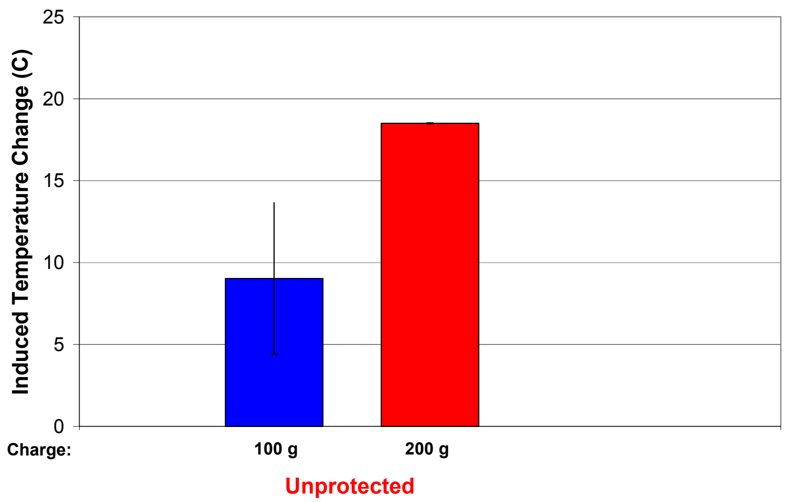

Figure 45: Induced Temperature Change From Blast on Dummy Hand

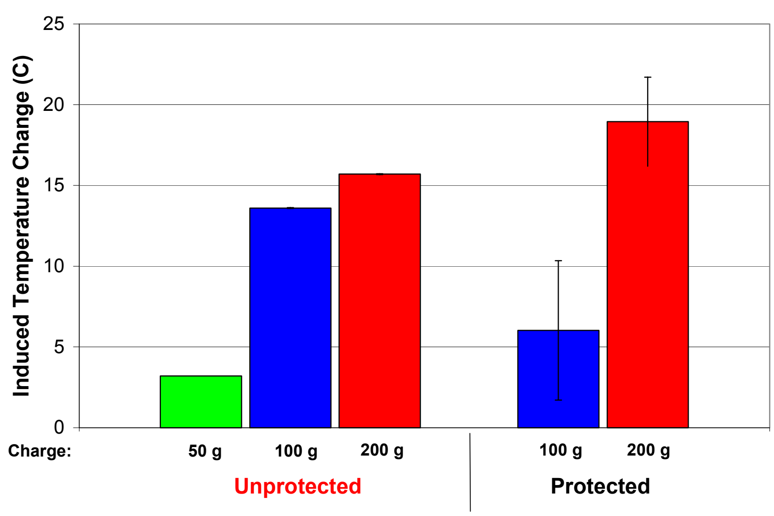

Figure 46: Induced Temperature Change From Blast on Dummy Chin

4. Conclusions and Future Work

To summarize, essential elements in the development of a procedure for evaluating the risk of injury while wearing demining protective equipment are:

- Repeatable, quantifiable threat (mine) – with fixed burial and soil characteristics.
- Robust dummy surrogate with established and applicable injury criteria – positioned in a realistic manner in positions representative of demining (i.e. kneeling and prone).
- Accurate positioning – distance to mine must be consistent and quantifiable.
- Robust instrumentation – data handling consistent with the response.
- Reasonable threat level that appropriately identifies the level of protection.

Each of these elements acts to provide an objective criterion for injury and injury performance while ensuring that the resulting criterion is as applicable as possible to the conditions experienced in the real world.

Each of these elements was satisfied in this proposed test methodology. The simulated mines show repeatable pressure time histories, and the largest simulated mine is comparable to an actual mine of the same threat level. Mine burial can be controlled very precisely, and soil characteristics have been fixed.

The Hybrid III dummy has been found to be a robust and repeatable surrogate. None of the dummies used suffered a significant mechanical failure during the testing. The dummies are available in sizes that are anthropometrically similar to a human mid-sized male and similar to a small female. Positioning was accomplished to within ±3 mm relative to the center of the mine with an inexpensive measurement device. Both the kneeling and the prone positions were specified to produce a significant risk of blunt head trauma to an unprotected dummy.

At first glance, it appears that the prone position has a higher risk of neck injury than does the kneeling position. However, it is important to realize the significant difference in nose-to-mine distance for the two positions. For the kneeling position, the dummy's nose-to-mine distance is 65 cm, whereas for the prone position, the distance is reduced to 45 cm. The two positions were **not** selected so that the injury risks for the head, neck, and thorax were nearly equivalent, **but** to directly compare risk of injury between the kneeling and prone positions.

Most of the instrumentation proved robust. For the head and chest accelerometers, the only failures arose from inadvertent wire separation. The head accelerations experienced by the dummies showed a substantial risk of serious head injury from blunt trauma for the larger mines. However, questions remain about the applicability of typical acceleration based injury criteria to mine blasts. *It is recommended that a limited test series be performed with an injury model under blast loading to determine the boundaries of applicability of the currently used injury criteria.*

The neck sensors performed well. The neck showed forcing similar to that seen in automobile impacts for which the sensors were developed. The sensor data showed good differentiation between the level of mine, and was repeatable within a test dummy. The loosening of the neck of

Dummy B compromised the comparison of Dummy A to Dummy B for neck loading. This indicates the large vibration loads in blast shock loading, not seen in the usual automotive application. For future tests, it is strongly recommended that the dummy neck tensioning be checked regularly during the test series.

The thoracic instrumentation proved generally robust. However, neither the chest displacement nor the Viscous Criterion showed injurious values, even for an unprotected dummy. The sternal accelerometers performed poorly, likely owing to high frequency oscillations in the sternum under blast loading. In future testing, the accelerometer should be mounted on the top of the sternum to avoid some of these oscillations. The upper thoracic pressure sensors proved robust, while the lower pressure sensors failed repeatedly. This may be the result of the greater compliance of the Hybrid III dummy in the lower thorax. All PPEs but one reduced the peak thoracic pressure for both the 100 g and 200 g charge size.

The ear pressure sensors proved relatively robust. Surprisingly, two PPEs with the largest helmets showed increased ear peak pressures relative to the unprotected dummy. This may be attributed to the helmets capturing the pressure wave.

Burn sensors used on the dummy hand and chin in this testing showed a very small risk of serious burns for the mines and depth of burial used. As the sensors are exceedingly delicate for blast testing, it is recommended that no burn sensors be used in subsequent testing.

Finally, this testing showed the strong effect of the blast cone induced by the geometry of the mines and simulated mines. This conical blast pattern limited the risk of injury to the thorax in both the kneeling and the prone positions. To provide the most comprehensive understanding of this effect, a small test series should be performed to quantify dummy response as a function of position in the blast cone.

Design of personal protective equipment against fragment and blast damage when demining involves numerous tradeoffs between protection of various types and ease of use. Such tradeoffs underscore the value of a complete assessment of PPE function that includes ergonomics, protection against fragments and protection against blunt trauma.

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Appendix A

Shot #, Dummy A	Charge Size	Suit/ Helmet	Pos.	Vert Nose (cm)	Vert Sternum (cm)	Horiz Nose	Horiz Sternum	Face Shield-Mine (cm)	Armor-Mine (cm)
BASELINE 1	50 g	None	K	61.1	42.2	22.2	42.1	NA	NA
BASELINE 3	100 g	None	K	61.1	42.2	22.2	42.2	NA	NA
BASELINE 5	100 g	None	K	63.4	42.2	29.6	48.7	NA	NA
BASELINE 7	50 g	None	K	63.4	42.2	29.6	48.7	NA	NA
BASELINE 9	100 g	None	K	63.4	42.2	29.6	48.7	NA	NA
BASELINE 11	200 g	None	K	63.4	42.2	29.6	48.7	NA	NA
BASELINE 13	200 g	None	K	63.4	42.2	29.6	48.7	NA	NA
SHOT 1B	200 g	PPE 1	K	63.4	42.2	29.6	48.7	24.2	49.0
SHOT 1D	100 g	PPE 1	K	63.4	42.2	29.6	48.7	22.0	44.0
SHOT 2A	100 g	PPE 2	K	63.4	42.2	29.6	48.7	22.5	45.0
SHOT 2K	100 g	PPE 2	K	63.4	42.2	29.6	48.7	22.5	45.0
SHOT 2M	200 g	PPE 2	K	63.4	42.2	29.6	48.7	22.5	45.0
SHOT 3A	200 g	PPE 3	K	63.4	42.2	29.6	48.7	23.2	42.6
SHOT 3B	100 g	PPE 3	K	63.4	42.2	29.6	48.7	23.2	42.6
SHOT 3B-D	200 g	PPE 3	K	63.4	42.2	29.6	48.7	23.2	44.0
SHOT 4A	200 g	PPE 4	K	63.4	42.2	29.6	48.7	21.8	48.2
SHOT 4B	200 g	PPE 4	K	63.4	42.2	29.6	48.7	21.8	48.2
SHOT 4D	100 g	PPE 4	K	63.4	42.2	29.6	48.7	21.8	48.2
SHOT 4D-F	100 g	PPE 4	K	63.4	42.2	29.6	48.7	21.8	48.2
SHOT 5B	100 g	PPE 5	K	63.4	42.2	29.6	48.7	21.3	47.0
SHOT 5D-B	200 g	PPE 5	K	63.4	42.2	29.6	48.7	21.3	47.0
SHOT 5F	200 g	PPE 5	K	63.4	42.2	29.6	48.7	21.3	47.0
BASELINE 14	100 g	None	P	33.2	19	50	67.7	NA	NA
BASELINE 16	200 g	None	P	33.2	19	50	67.7	NA	NA
BASELINE 18	200 g	None	P	33.2	19	37.5	54.8	NA	NA
BASELINE 20	100 g	None	P	33.2	19	30.5	50	NA	NA
BASELINE 22	200 g	None	P	33.2	19	30.5	50	NA	NA
BASELINE 24	100 g	None	P	33.2	19	30.5	50	NA	NA
BASELINE 26	50 g	None	P	33.2	19	30.5	50	NA	NA
SHOT 1G	100 g	PPE 1	P	33.2	19	30.5	NA	25.8	46.5
SHOT 1I-G	100 g	PPE 1	P	33.2	19.0	30.5	NA	25.8	46.5
SHOT 1J-G	200 g	PPE 1	P	33.2	19.0	30.5	NA	25.8	46.5
SHOT 2O	200 g	PPE 2	P	33.2	19.0	30.5	NA	26.5	48.5
SHOT 2Q-O	200 g	PPE 2	P	33.2	19.0	30.5	NA	26.5	49.0
SHOT 2O-S	100 g	PPE 2	P	33.2	19.0	30.5	NA	26.5	49.0
SHOT 3G	100 g	PPE 3	P	33.2	19.0	30.5	NA	24.7	48.0
SHOT 3G-I	100 g	PPE 3	P	33.2	19.0	30.5	NA	24.7	48.0
SHOT 3G-J	200 g	PPE 3	P	33.2	19.0	30.5	NA	24.7	48.0
SHOT 4G	200 g	PPE 4	P	33.2	19.0	30.5	48.5	21.4	NA
SHOT 4G-I	200 g	PPE 4	P	33.2	19.0	30.5	48.5	21.5	NA
SHOT 4G-J	100 g	PPE 4	P	33.2	19.0	30.5	48.5	21.5	NA
SHOT 5H (NO DATA)	100 g	PPE 5	P	33.2	19.0	30.5	NA	20.4	39.6
SHOT 5H-J	100 g	PPE 5	P	33.2	19.0	30.5	NA	21.4	39.6
SHOT 5H-K	100 g	PPE 5	P	33.2	19.0	30.5	NA	21.4	39.6
SHOT 5H-M	200 g	PPE 5	P	33.2	19.0	30.5	NA	21.4	39.6
PMN-1	NA	PPE 3	P	33.2	19.0	30.5	NA	23.3	48.5
PMN-2	NA	PPE 3	P	33.2	19.0	30.5	NA	24.7	48.0
PMN-3	NA	PPE 3	P	33.2	19.0	30.5	NA	24.7	48.0
PMN-4	NA	PPE 2	P	33.2	19.0	30.5	NA	27.2	48.5
PMN-5	NA	PPE 2	P	33.2	19.0	30.5	NA	27.2	48.5
PMN-7	NA	PPE 3	K	63.4	42.2	29.6	NA	23.2	42.6
PMN-8	NA	PPE 3	K	63.4	42.2	29.6	NA	23.2	42.6
PMN-9	NA	PPE 2	K	63.4	42.2	29.6	NA	26.3	47.5
PMN-10	NA	PPE 2	K	63.4	42.2	29.6	NA	27.2	48.5

Table 7: Measurements and Shot Parameters for Dummy A (Hybrid III 50^{th} % male)

Shot #, Dummy B	Charge	PPE	Pos.	Vert Nose	Vert Sternum	Horiz Nose	Horiz Sternum	Face Shield-Mine	Armor-Mine
BASELINE 2	100 g	None	K	61.1	42.2	22.2	42.1	NA	NA
BASELINE 4	50 g	None	K	61.1	42.2	22.2	42.1	NA	NA
BASELINE 6	100 g	None	K	63.4	42.2	29.6	48.7	NA	NA
BASELINE 8	200 g	None	K	63.4	42.2	29.6	48.7	NA	NA
BASELINE 10	50 g	None	K	63.4	42.2	29.6	48.7	NA	NA
BASELINE 12	50 g	None	K	63.4	42.2	29.6	48.7	NA	NA
SHOT 1A	200 g	PPE 1	K	63.4	42.2	29.6	48.7	21.5	44.5
SHOT 1C	200 g	PPE 1	K	63.4	42.2	29.6	48.7	23.4	43.7
SHOT 1E	100 g	PPE 1	K	63.4	42.2	29.6	48.7	22.0	44.0
SHOT 1F	100 g	PPE 1	K	63.4	42.2	29.6	48.7	22.0	44.0
SHOT 2B	100 g	PPE 2	K	63.4	42.2	29.6	48.7	22.5	45.0
SHOT 2L	200 g	PPE 2	K	63.4	42.2	29.6	48.7	23.5	45.0
SHOT 2N	200 g	PPE 2	K	63.4	42.2	29.6	48.7	23.5	45.0
SHOT 3C	100 g	PPE 3	K	63.4	42.2	29.6	48.7	23.6	42.5
SHOT 3C-E	100 g	PPE 3	K	63.4	42.2	NA	48.7	23.6	42.5
SHOT 3F	200 g	PPE 3	K	63.4	42.2	29.6	48.7	23.6	42.5
SHOT 4C	200 g	PPE 4	K	63.4	42.2	29.6	48.7	21.8	48.2
SHOT 4E	100 g	PPE 4	K	63.4	42.2	29.6	48.7	22.0	48.2
SHOT 5A	100 g	PPE 5	K	63.4	42.2	29.6	48.7	21.2	48.7
SHOT 5C	100 g	PPE 5	K	63.4	42.2	29.6	48.7	21.2	47.7
SHOT 5E-C	200 g	PPE 5	K	63.4	42.2	29.6	48.7	21.2	47.7
BASELINE 15	50 g	None	P	33.2	19	50	67.6	NA	NA
BASELINE 17	100 g	None	P	33.2	19.0	50.0	67.6	NA	NA
BASELINE 19	100 g	None	P	33.2	19.0	37.5	54.7	NA	NA
BASELINE 21	200 g	None	P	33.2	19.0	30.5	49.0	NA	NA
BASELINE 23	200 g	None	P	33.2	19.0	30.5	50.0	NA	NA
BASELINE 25	100 g	None	P	33.2	19.0	30.5	50.0	NA	NA
BASELINE 27	50 g	None	P	33.2	19.0	30.5	49.0	NA	NA
BASELINE 28	50 g	None	P	33.2	19.0	30.5	49.0	NA	NA
SHOT 1H	100 g	PPE 1	P	33.2	19.0	30.5	NA	23.2	40.5
SHOT 1H-K	200 g	PPE 1	P	33.2	19.0	30.5	NA	24.4	48.2
SHOT 1H-L	200 g	PPE 1	P	33.2	19.0	30.5	NA	24.4	48.2
SHOT 2P	200 g	PPE 2	P	33.2	19.0	30.5	NA	25.6	48.5
SHOT 2P-R	100 g	PPE 2	P	33.2	19.0	30.5	NA	25.6	48.0
SHOT 2P-T	100 g	PPE 2	P	33.2	19.0	30.5	NA	25.6	48.0
SHOT 3H	100 g	PPE 3	P	33.2	19.0	30.5	NA	24.7	48.5
SHOT 3H-K	200 g	PPE 3	P	33.2	19.0	30.5	NA	24.7	48.5
SHOT 3H-L	200 g	PPE 3	P	33.2	19.0	30.5	NA	24.7	48.5
SHOT 4H	200 g	PPE 4	P	33.2	19.0	30.5	49.0	23.8	NA
SHOT 4H-K	100 g	PPE 4	P	33.2	19.0	30.5	49.0	22.8	NA
SHOT 4H-L	100 g	PPE 4	P	33.2	19.0	30.5	49.0	23.8	NA
SHOT 5I	100 g	PPE 5	P	33.2	19.0	30.5	49.0	23.3	48.6
SHOT 5I-L	200 g	PPE 5	P	33.2	19.0	30.5	NA	23.3	48.6
SHOT 5I-N	200 g	PPE 5	P	33.2	19.0	30.5	NA	23.3	48.6
PMN-6	NA	PPE 3	K	63.4	42.2	29.6	NA	23.6	42.5

Table 8: Measurements and Shot Parameters for Dummy B (Hybrid III 50^{th} % male)

Shot #	Charge	PPE	Pos.	Vert Nose	Vert Sternum	Horiz Nose	Horiz Sternum	Face Shield-Mine	Armor-Mine
SHOT 6A	100 g	PPE 2	K	63.4	42.2	29.6	48.7	23.6	41.3
SHOT 6B	200 g	PPE 2	K	63.4	42.2	29.6	48.7	23.6	41.3
SHOT 6C	200 g	PPE 2	K	63.4	42.2	29.6	48.7	23.6	41.3
SHOT 6D	200 g	PPE 2	K	63.4	42.2	29.6	48.7	23.6	41.3

Table 9: Measurements and Shot Parameters for Hybrid III 5th % Female

Key to Tables:

Pos. = Position (K = kneeling, P = Prone)
Vert Nose = Vertical distance from the nose to the mine top center
Vert Sternum = Vertical distance from the center of the sternum to the mine top center
Horiz Nose = Horizontal distance from the nose to the mine top center
Horiz Sternum = Horizontal distance from the center of the sternum to mine top center
Face Shield-Mine = Distance from the face shield to the mine (where appropriate)
Armor-Mine = Distance from the armor to the mine (where appropriate)

Appendix B

This appendix contains drawings and photographs of dummy modifications for enhanced bending to allow a Hybrid III 50th % male to assume a realistic prone position. Dummy modifications are discussed in Section 2 above.

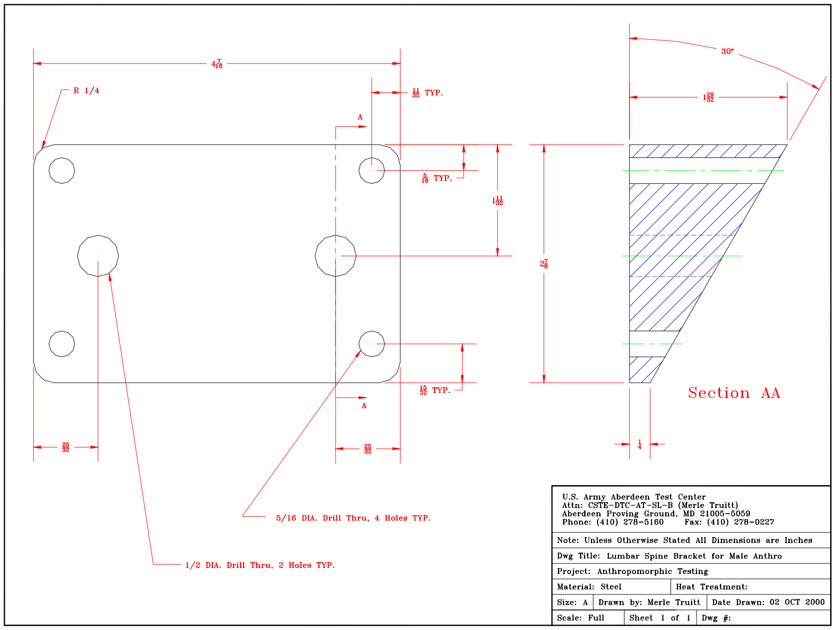

Figure 47: Lumbar Spine Wedge for Prone Position

Figure 48: Photograph of Lumbar Spine Wedge

Figure 49: Photograph of Unmodified (Left) and Modified (Right) Dummy Neck Bracket

Appendix C

SHOT #, DUMMY A	CHARGE	CHARGE WEIGHT (g)	BOOSTER WEIGHT (g)	SHOT #, DUMMY B	CHARGE	CHARGE WEIGHT (g)	BOOSTER WEIGHT (g)
BASELINE 1	50 g	NM	NM	BASELINE 2	100 g	NM	NM
BASELINE 3	100 g	100.005	1.855	BASELINE 4	50 g	100.000	NM
BASELINE 5	100 g	100.005	1.935	BASELINE 6	100 g	100.000	1.960
BASELINE 7	50 g	50.010	1.895	BASELINE 8	200 g	199.970	1.940
BASELINE 9	100 g	100.005	1.850	BASELINE 10	50 g	50.000	1.900
BASELINE 11	200 g	199.400	1.990	BASELINE 12	50 g	50.000	NM
BASELINE 13	200 g	200.005	0.930	SHOT 1A	200 g	200.010	0.940
SHOT 1B	200 g	200.015	0.930	SHOT 1C	200 g	200.100	0.945
SHOT 1D	100 g	100.000	0.910	SHOT 1E	100 g	100.010	0.945
SHOT 2A	100 g	100.055	1.860	SHOT 1F	100 g	100.085	1.860
SHOT 2K	100 g	100.065	1.860	SHOT 2B	100 g	100.000	1.860
SHOT 2M	200 g	200.015	1.860	SHOT 2L	200 g	200.020	1.860
SHOT 3A	200 g	200.035	1.860	SHOT 2N	200 g	200.045	1.860
SHOT 3B	100 g	100.020	1.860	SHOT 3C	100 g	100.025	1.860
SHOT 3B-D	200 g	200.025	1.860	SHOT 3C-E	100 g	100.015	1.860
SHOT 4A	200 g	200.005	1.860	SHOT 3F	200 g	200.015	1.860
SHOT 4B	200 g	200.015	1.860	SHOT 4C	200 g	200.020	1.860
SHOT 4D	100 g	100.015	1.860	SHOT 4E	100 g	100.020	1.860
SHOT 4D-F	100 g	100.010	1.860	SHOT 5A	100 g	100.025	1.860
SHOT 5B	100 g	100.025	1.860	SHOT 5C	100 g	100.035	1.860
SHOT 5D-B	200 g	200.010	1.860	SHOT 5E-C	200 g	200.045	1.860
SHOT 5F	200 g	200.025	1.860	NA	NA	NA	NA
BASELINE 14	100 g	100.000	1.860	BASELINE 15	50 g	50.000	1.860
BASELINE 16	200 g	200.030	1.860	BASELINE 17	100 g	100.070	1.860
BASELINE 18	200 g	200.040	1.860	BASELINE 19	100 g	100.050	1.860
BASELINE 20	100 g	100.060	1.860	BASELINE 21	200 g	200.030	1.860
BASELINE 22	200 g	200.025	1.860	BASELINE 23	200 g	200.000	1.860
BASELINE 24	100 g	100.010	1.860	BASELINE 25	100 g	100.016	1.860
BASELINE 26	50 g	50	1.860	BASELINE 27	50 g	50.005	1.890
SHOT 1G	100 g	100.010	1.860	BASELINE 28	50 g	50.005	1.860
SHOT 1I-G	100 g	100.005	1.860	SHOT 1H	100 g	100.000	1.860
SHOT 1J-G	200 g	200.045	1.860	SHOT 1H-K	200 g	200.035	1.860
SHOT 2O	200 g	200.006	1.905	SHOT 1H-L	200 g	200.025	1.860
SHOT 2Q-O	200 g	200.015	1.860	SHOT 2P	200 g	200.040	1.860
SHOT 2O-S	100 g	100.010	1.860	SHOT 2P-R	100 g	100.005	1.860
SHOT 3G	100 g	100.000	1.860	SHOT 2P-T	100 g	100.000	1.860
SHOT 3G-I	100 g	100.010	1.860	SHOT 3H	100 g	100.010	1.860
SHOT 3G-J	200 g	200.005	1.860	SHOT 3H-K	200 g	200.000	1.860
SHOT 4G	200 g	200.005	1.860	SHOT 3H-L	200 g	200.000	1.860
SHOT 4G-I	200 g	200.005	1.860	SHOT 4H	200 g	200.005	1.860
SHOT 4G-J	100 g	100.005	1.860	SHOT 4H-K	100 g	100.005	1.860
SHOT 5H (NO DATA)	100 g	100.005	1.860	SHOT 4H-L	100 g	100.005	1.860
SHOT 5H-J	100 g	100.005	1.860	SHOT 5I	100	1.860	62.000
SHOT 5H-K	100 g	100.000	1.800	SHOT 5I-L	200 g		
SHOT 5H-M	200 g	199.990	1.930	SHOT 5I-N	200 g		
				SHOT 6A	100 g	100.005	1.770
				SHOT 6B	200 g	200.000	1.870
				SHOT 6C	200 g	200.030	1.860
				SHOT 6D	200 g	200.005	1.840

Table 10: Charge Masses for Mines and Detonators

Appendix D

PPE and glove damage suffered during the mine blasts.

SHOT #, DUMMY A	HEADGEAR RESULTS	BODY ARMOR RESULTS	GLOVE RESULTS	SHOT #, DUMMY B	HEADGEAR RESULTS	BODY ARMOR RESULTS	GLOVE RESULTS
Baseline 13				Shot 1A	-visor skin pitted, ripped, and perfed -visor pitted/visor lost	-peppering	-none
Shot 1B	-visor severed into 4 large pieces	-peppering	-R: index finger holed, thumb exposed	Shot 1C	-visor lost, severed into several pieces	-peppering at chest & collar/L shaped tear	-L: palm, thumb, index, and middle fingers exposed
Shot 1D	-visor skin pitted, and perfed -visor pitted -visor lost	-peppering at collar	-L: back of hand, thumb, index, middle fingers exposed	Shot 1E	-visor skin pitted, cracked, and perfed -visor pitted -visor lost	-peppering -20cm tear at bottom	-L: top of hand and thumb exposed
Shot 2A	-visor lost -face shield partially detached from headstrap	-lightly peppered at collar -one 3cm hole at collar	-R: outer glove fully ripped/inner glove index finger and palm exposed	Shot 1F	-visor lost, lightly pitted	-lightly peppered	-L: outer glove ripped at thumb, inner intact
Shot 2K	-face shield detached from headstrap on one side -visor pitted, mostly at top	-peppered at collar -hole at right side of collar, similar to last shot 2cm	-L: outer ripped at thumb and index finger/inner intact R: both intact, 3mm burn through both gloves above thumb	Shot 2B	-headstrap detached from face shield at right side and top of headstrap broken apart -faceshield pitted	-apron peppered especially at collar and wings (more on right side)	-L: outer glove ripped between thumb and index finger
Shot 2M	-faceshield lost, headstrap remained on dummy head (both attachment points failed) - severe pitting	-severe peppering at collar and wings.	-R: outer ripped all over/inner ripped at thumb and index finger	Shot 2L	-faceshield detached from headstrap -visor lost - faceshield pitted top center	-apron peppered at wings and collar -hole in collar center 4cm	-L: top of hand exposed -R: outer glove ripped at top of hand
Shot 3A	-pitting on top center of visor	-peppered on front balllistic insert -3 holes in jacket outer layer at balllistic insert perimeter (corner)	-L: outer glove ripped bet thumb and index finger -R: both gloves ripped to shreds	Shot 2N	-visor 275 cm to left of dummy on ground -headstrap 163 cm to right on ground -R & L positioning knobs missing -top of headstrap still functional	-peppered at wings, top center, collar -3 holes in collar, 1cm ea -2 hole at right wing 1cm	-L: outer glove ripped between thumb and index finger -R: outer ripped on hand

SHOT #, DUMMY A	HEADGEAR RESULTS	BODY ARMOR RESULTS	GLOVE RESULTS	SHOT #, DUMMY B	HEADGEAR RESULTS	BODY ARMOR RESULTS	GLOVE RESULTS
Shot 3B	-pitted upper center of visor	-peppered on upper center of balllistic insert -holes in outer layer of jacket and in outer fabric layer in balllistic insert at upper perimeter	L: pin hole in outer glove R: thumb exposed	Shot 3C	pitting at top of visor	-peppering and holing on outer shells of jacket and balllistic insert -no perf	-L: thumb and palm exposed
Shot 3B-D	-helmet cracked down center line seam -visor pitted top center	-holes in outer layer of jacket and in outer fabric layer in balllistic insert at upper perimeter -front balllistic insert pitted -no perf	-L: pinhole through both gloves -R: outer layer ripped at top of hand	Shot 3C-E	-upper visor peppered	-holes in outer layer of jacket and in outer fabric layer in balllistic insert at upper perimeter -front balllistic insert pitted	-L: outer glove completely ripped, palm, thumb, and index finger explosed
Shot 4A	-visor broke from helmet and landed on the ground 450cm behind dummy -visor severed into several pieces and pitted -helmet slightly pitted at front -blast appears to have come up under visor -headstraps broken	-straps on shoulders came unvelcroed -peppered at top center and wings -outer layer holed	-R: both gloves severely compromised -hand ended up under suit after the shot	Shot 3F	-1 perforation in top center of visor -pitting in visor	-holes in outer layer of jacket and in outer fabric layer in balllistic insert at upper perimeter -front balllistic insert pitted	-L: thumb and index finger exposed -R: outer glove ripped at top of hand
Shot 4B	-visor dimpled on inside in 1 place -visor remained attached during shot, but came apart during removal from dummy head -visor pitted top center -helmet pitted and metal visor attachment frame bent	-outer layer peppered and ripped top, center and at wings -some holing through to 2nd layer of blue fabric	-R: whole hand exposed	Shot 4C	-whole helmet blown off head and landed at mine area -rear headstraps broken -top half of visor pitted -R metal visor attachement frame bolt detached	-peppered at chest and wings	-L: palm, index finger and thumb exposed
Shot 4D	-L headstrap assy broken -pitting helmet front -pitting top center visor	-R collar unfastened -small burn on R wing -minimal peppering top, center and wings		Shot 4E	-helmet and visor pitted at center -helmet headstraps broken	-peppering on left side of vest and collar, outer layer of fabric holed -no perfs in armor	-L: index finger and thumb and top of hand exposed
Shot 4D-F	-headstraps unfastened still functional -helmet and visor pitted in front center	-peppering on outer blue fabric, wings, top, and center	-R: outer glove ripped between thumb and index finger	Shot 5A	-only minor peppering on visor	-shoulder panels unsnapped from vest -bottom left side panel unstitched -minor peppering to vest collar	-L: outer glove ripped at thumb and index finger

SHOT #, DUMMY A	HEADGEAR RESULTS	BODY ARMOR RESULTS	GLOVE RESULTS	SHOT #, DUMMY B	HEADGEAR RESULTS	BODY ARMOR RESULTS	GLOVE RESULTS
Shot 5B	-minor pitting on visor and helmet	-shoulder panels unsnapped from vest -groin protector unvelcroed -peppering on collar only -wing attachments partially unstitched		Shot 5C	-minor pitting on visor	-shoulder panels unsnapped from vest -R arm panel unvelcroed -R wing attachments unstitched -no peppering	-L: thumb, palm, and index finger exposed
Shot 5D-B	-helmet crooked on head -chin strap unfastened -visor stuck in place -pitting on center visor and helmet	- shoulder panels unsnapped from vest -R wing and collar unfastened -collar seam ripped on top and bottom -wing seams unstitched -minor peppering on body and R arm	-L: thumb exposed	Shot 5E-C	- pitting on visor - right top edge of visor chipped -L visor securing washer bent	-shoulder panels unsnapped from vest -L wing velcro undone -L shoulder small hole -collar peppered and minimal holing in outer fabric -wing panels unstitched	-L: top of hand, palm, thumb and index finger exposed
Shot 5F	-visor pitted -helmet pitted and gashed in 2 places	-all snaps unfastened -R sleeve velcro undone -minimal peppering -2 holes in collar outer fabric -collar unstitched at top and bottom	-L: thumb and index finger exposed	NA			
Shot 1G	-faceshield broke into several large pieces -found approx 6 ft from mine	-peppering at shoulder level -no perfs	no gloves	Baseline 28			
Shot 1I-G	-faceshield broke into several large pieces -found approx 178cm to 460 cm from mine, mostly to the rear of the dummy -visor skin unattached on one side and holed and pitted	-peppering at shoulder level -no perfs	-L: small hole at tip of index finger -R: hole in thumb of outer glove	Shot 1H	-visor to left front of dummy, 70 cm from mine -visor skin detached from right side -visor broken into several pieces	-minor peppering at chest area	
Shot 1J-G	-visor pitted and 340 cm in front of dummy on ground -visor skin holed -no perf	-left collar unstitched and ripping in the same area -peppering esp. at shoulder	-L: index finger exposed -hole through both gloves on thumb -R: outer glove ripped and holes in inner glove exposing thumb	Shot 1H-K	-visor blown off head, headstrap 18’2” right front of mine, visor skin 4’10” right front -visor shattered into several pieces spread out in 18’ radius around mine	-peppering at shoulder and upper chest level -1” tear at left shoulder	

SHOT #, DUMMY A	HEADGEAR RESULTS	BODY ARMOR RESULTS	GLOVE RESULTS	SHOT #, DUMMY B	HEADGEAR RESULTS	BODY ARMOR RESULTS	GLOVE RESULTS
Shot 2O	-headstrap behind dummy -visor 730cm front ground -pitting top center	-peppering at collar and wings -large hold at right shoulder	-hands rotated outward at wrists -R: index finger and thumb exposed	Shot 1H-L	-headstrap remained -visor skin detached at right -visor broken into several pieces 12' radius from mine	-ripped in several places on collar and shoulders -heavy peppering	
Shot 2Q-O	-headstrap on dummy posterior -visor 285cm to right front on ground -visor pitted front center	-peppering on shoulders, wings, and collar	-R: thumb and index finger exposed	Shot 2P	-headstrap remained -visor 18'8" left front of mine on ground in 1 piece -pitted at top center	-R & L seams ripped at wings -peppering at sholders	-L: index and middle fingers exposed
Shot 2O-S	-headstrap remained -visor 7' front right of mine -visor pitted front center	-same vest-additional peppering at collar		Shot 2P-R	-headstrap remained -visor 1' to right front of mine -visor pitted center	-same vest-additional tearing on left 1"	-L: outer glove ripped at index and middle fingers
Shot 3G	-minimal pitting on visor -helmet cracked down center seam	-no apparent peppering	-L: outer glove ripped at palm -R: thumb and index finger exposed	Shot 2P-T	-headstrap remained -visor 3' right front of mine -visor pitted center	-same vest -no apparent additional damage	-L: outer glove ripped at middle and index fingers
Shot 3G-I	-visor pitted top center	-1cm hole in L shoulder outer fabric -minor peppering on both shoulders	-R: index finger exposed	Shot 3H	-pitting on visor	-no peppering	-L: small hole in tip of middle finger in outer glove
Shot 3G-J	-visor pitted and broken into several pieces and broken off at R attachment point -helmet cracked down center seam and at L attachment point	-same jacket, some additional peppering	-R: outer and inner gloves severely ripped	Shot 3H-K	-helmet cracked down center seam -visor pitted mostly top center	-very minor peppering at shoulder level	-L: small hole in both gloves at index finger tip, small hole in outer glove at middle finger tip -R: small holes in both gloves at thumb and index finger
Shot 4G	-visor in sand pit -metal visor attachment strip deformed and 3 rivet nuts sheared off -visor severed from top to bottom down center of visor -helmet pitted -head straps unfastened	-peppered around collar -armor hangs low around neck, exposing upper chest		Shot 3H-L	-helmet cracked down center seam -top center of visor heavily pitted -one dimple on inside of visor, no perf	-ripped at collar interface with jacket -peppering -hole on collar through outer fabric	-R: outer glove ripped at palm, thumb and index finger, inner glove peppered

SHOT #, DUMMY A	HEADGEAR RESULTS	BODY ARMOR RESULTS	GLOVE RESULTS	SHOT #, DUMMY B	HEADGEAR RESULTS	BODY ARMOR RESULTS	GLOVE RESULTS
Shot 4G-I	-visor in sand pit -metal visor attachment strip deformed and 3 rivet nuts sheared off -R visor adjustment point deformed -pitting on helmet and visor -head straps broken and unfastened	-small burn on collar -peppering		Shot 4H	-metal visor attachment strip deformed and 1 L nut sheared off -helmet and visor pitted -head straps unfastened	-collar and upper chest area light peppering	-L: hand blown upward, index and middle fingers exposed -R: thumb tip exposed
Shot 4G-J	-metal visor attachment strip deformed and outer rivet nuts sheared off -pitting on visor	-collar and shoulders peppered	-L: arm rotated outward at elbow	Shot 4H-K	-metal visor attachment strip deformed and 1 R nut sheared off -helmet and visor pitted -head straps unfastened	-collar lightly peppered	-L: outer glove ripped at middle finger, small holes in outer glove
Shot 5H (NO DATA)				Shot 4H-L	-metal visor attachment strip deformed and 1 R nut sheared off - visor pitted	-collar lightly peppered	-L: index and middle fingers exposed -R: outer glove ripped at thumb and index finger
Shot 5H-J	-helmet rotated clockwise on head and chinstrap unsnapped -L visor adjustment pin cracked -very minor pitting	-small spot of peppering at collar	-R hand rotated outward at wrist	Shot 5I	-visor blown upward to expose face -chin guard blown off chin -minor pitting to visor center	-R shoulder panel unsnapped	-L: outer glove ripped at index finger
Shot 5H-K	-helmet rotated ccw -minimal pitting of visor and front of helmet	-minimal peppering at collar and shoulders		Shot 5I-L	-helmet rotated ccw -minimal pitting on visor and front of helmet -strap connector piece broken/head strap came apart	-no apparent peppering	-L: both gloves shredded
Shot 5H-M	-helmet lost in sand pit -chin strap unsnapped -helmet and visor pitted	-L shoulder unsnapped -minor peppering at collar & shoulders -R & L sleeve seams ripped	-L: thumb, index, and middle fingers exposed -R: thumb and index finger exposed	Shot 5I-N	-pitting on visor and helmet	-minor peppering collar and shoulders -collar seam ripped, bottom L -L & R sleeve seams ripped	-R: thumb exposed and hand rotated outward at wrist
PMN-1	no notes			NA			

SHOT #, DUMMY A	HEADGEAR RESULTS	BODY ARMOR RESULTS	GLOVE RESULTS	SHOT #, DUMMY B	HEADGEAR RESULTS	BODY ARMOR RESULTS	GLOVE RESULTS
PMN-2	-visor severed into several pieces -helmet cracked down the center seam			PMN-6	-visor severed into several pieces -helmet cracked in front, horizontally		
PMN-3	-visor severed into several pieces -front of helmet appears to have permanent deformation-flattened out in vertical			NA			
PMN-4	-visor came off headstrap in 1 piece -landed in san pit several ft from mine -visor pitted	-peppering on shoulders		NA			
PMN-5	-visor in 1 piece on ground directly in front of fixture (table) -headstrap remained on dummy head			NA			
PMN-7	-pitting	-severed body armor front plate (upper L corner) -severe holing in upper area of fabric over body armor		Shot 6A	-visor pitted top center	-peppering at front plate shield area	
PMN-8	-visor severed in half & shattered along top edge -helmet cracked horizontally in front and at visor attachment point -partial penetration on visor back side in several places	-front panel pitted and broken horizontally into several pieces		Shot 6B	-sever pitting at visor top center -partial penetration on backside of visor -helmet cracked down the center along seam	-same suit -additional peppering and holes in fabric -front balllistic insert pitted at upper edge	
PMN-9	-visor detached from headstrap and landed in sand pit at mine -headstrap landed under table behind dummy -partial penetration on back side of visor at bottom center	-sever peppering/ holing of apron fabric		Shot 6C	-severe peppering visor top center	-same suit -additional front panel pitting	
PMN-10	-visor came off in one piece -headstrap stayed on dummy head and was broken	-severely ripped		Shot 6D	-severe pitting ***-complete penetration*** on visor	-same suit -additional front panel pitting	

Table 11: Post Test Condition of PPE Armors, Helmets and Latex Gloves

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